INDUSTRIAL
FURNACES
VOL. II

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BY

W. TRINKS

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INDUSTRIAL FURNACES

VOLUME II

FUELS, FURNACE TYPES AND FURNACE EQUIPMENT; THEIR SELECTION, AND INFLUENCE UPON FURNACE OPERATION

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PREFACE

The present volume is a continuation of the first one, but is, nevertheless, complete in itself. While the first volume contains a great deal of theory and appeals mainly to the designer of furnaces, the present one is devoted primarily to practice, and should appeal to coordinators of existing designs. In that class are (1) men who have to decide on the type of fuel or heat energy to be used in a specific case, (2) those who select furnace equipment, (3) sales engineers of furnace equipment, (4) men who install furnaces, and (5) furnace operators. This fact notwithstanding, the designer of furnaces will find much in the present volume that is helpful.

In this volume a great deal of equipment has been described. For several reasons, no names of manufacturers have been mentioned in connection with any apparatus. In the first place, a reference book should not be a glorified trade catalog. Furthermore, this book, being the only treatise in existence on the subject, will probably be used in countries other than the United States, and in such countries the trade names of the "States" are practically unknown. Moreover, fundamental types have been selected for description as far as possible. Many of these types are made by several manufacturers, and equipment similar to that described herein may, during the life of the book, be introduced by additional manufacturers. In such cases it would be unfair to mention one manufacturer and to omit the others. Those who wish to purchase equipment similar to any type described can refer to buyers' guides, which are available in practically all countries. In the United States, books such as Thomas' "Register of American Manufacturers," Hendricks' "Commercial Register," and the advertising pages of the technical press give reliable up-to-date information.

Almost all of the equipment described in this volume was formerly protected by patents, is patented at the present time, or

will be granted patent protection in the near future. In explanation of this last statement, it may be mentioned that the granting of a patent often takes years, during which time outsiders have no knowledge of a pending patent application. Furthermore, some of the patents now in existence will probably be declared void by the courts. For these reasons, and because of the fact that the book is likely to be used outside of the United States, information on the patent status of the devices herein described has been omitted. The reader is advised to study the patent records, before copying any device mentioned in this book. Purchase of equipment from a reliable manufacturer places the responsibility upon the manufacturer and insures against untoward events arising from infringements.

In limiting descriptive matter to fundamental types, the author has tried to avoid getting lost in details, which vary from month to month. So far as late developments of design are concerned, it is obvious that any reference book must necessarily be obsolete before it has been printed, and that information concerning recent improvements must be obtained from current trade papers. The reference book is, nevertheless, indispensable. It supplies information and instruction with regard to fundamentals and enables the student to read trade papers critically—to read between the lines, as it were. What the trade papers print is generally true; but they dare not print everything that is true. For the same reason, this book should also be of assistance in the judging of papers on furnace equipment that may be read before technical societies. Such papers are frequently offered by commercial interests and are, in consequence, not wholly unbiased. Finally, this book may help those who wish to purchase furnace equipment and who have to listen to the conflicting stories of salesmen.

On account of the wide field covered by the subject of industrial furnaces, the author has found it necessary to supplement his own experience with that of other individuals. In consequence, this volume is based not only upon the personal observations of the author, but also on publications, and upon communications in which individuals and firms have stated their experiences. Although a few errors are likely to be found in such an aggregation of material from various sources, the statements in this book are believed to be substantially correct. A great part of the subject matter has been published piecemeal and has been

examined critically by those who are interested in industrial furnaces. The whole manuscript has been submitted, in sections and as a whole, to builders and users of furnaces.

The author wishes to thank all those who have contributed toward the making of this volume. It is almost impossible to mention individually everyone who has helped, because the correspondence carried on, for the purpose of gathering and sifting information, covered many countries and amounted to approximately one thousand letters. A special expression of gratitude is due Mr. J. A. Doyle, Vice President of the W. S. Rockwell Company, for reading the manuscript from beginning to end and for giving freely of his rich experience, and also to Mr. J. D. Keller, who shared in doing much of the detail work. It is hoped that this volume may find just as favorable a reception as the first one.

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INTRODUCTION

The function of industrial furnaces is to generate and apply heat in such a manner that the heated product will conform to certain specifications, with lowest cost of heating per unit of product.

The heat is generated either by combustion of fuel or by the conversion of electrical energy. The selection of that fuel which is best suited to a particular case necessitates the possession of knowledge concerning important properties of fuels and of the equipment needed for their preparation. Chapter I has been written with the aim of imparting that knowledge, together with information concerning the cost of a given amount of heat when produced by different fuels.

The devices for burning a fuel economically, with the correct quantity of air, vary widely with the nature of the fuel. Chapter II of the present volume deals exclusively with the equipment used to burn the different fuels and to convert electrical energy into heat. In that chapter, mention must of necessity be made of devices for controlling furnace temperature and furnace atmosphere; yet these same devices and the principles upon which they are based are important enough to be treated in separate chapters. Because of these facts, Chapter III has been devoted to the control of the temperature of the furnace and of the charge, while Chapter IV has been devoted to the effects of furnace atmosphere upon the charge and to the control of furnace atmosphere.

The requirement of low cost per unit of heated product has led to the development of a great variety of labor-saving devices in connection with furnaces, embracing the "handling" of the stock as well as the methods of furnace repair. In addition, automatic devices for bringing the fuel to the furnace, and for adjusting the supply of fuel to the requirements of the furnace, serve to economize labor. Chapter V deals with these devices in

considerable detail and rounds out the descriptions given in previous chapters.

Although " comparisons are odious," they must be made, if the right type of furnace and the right kind of fuel (or energy) are to be selected for different purposes. With this fact in mind, the author has written Chapter VI, which aims to offer a critical comparison of furnace types and of fuels (or energy supply). It is based upon all previous chapters, including those of Volume I.

Chapter VII, which follows logically from Chapter VI, deals with the methods which should be used in the selection of furnace types, kinds of fuel, and auxiliary equipment to suit plant conditions.

INDUSTRIAL FURNACES

VOL. II

CHAPTER I

FUELS

TYPES OF FUELS

In industrial furnaces, heat is liberated either by the combustion of fuel or by the conversion of electrical energy into heat. Unless the electrical energy is derived from falling water or from wind, it, likewise, is generated by the combustion of fuel, by way of the detour of generation of mechanical energy.

The following fuels are burned in industrial furnaces:

I. Gaseous fuels.
   - (*a*) Rich gases, such as natural gas, town (coal) gas, coke-oven gas, and water gas.
   - (*b*) Lean gases, such as producer gas, " carbo-gas " (mixed gas), or blast-furnace gas.
   - (*c*) Dirty gases, such as raw producer gas.

II. Liquid fuels.
   Gasoline, kerosene, light fuel oils, heavy fuel oils, tar.

III. Solid fuels.
   - (*a*) Powdered coal.
   - (*b*) Coke } on the grate.
   - (*c*) Coal } on the grate.

The principal properties of important fuels are given in Table I. On account of the unavoidable variations in the composition of fuels, the figures represent average values only.

TABLE I.—PROPERTIES OF FUELS

Fuel	Composition—Per Cent by Volume (62° F. and 14.7 lb. per sq. in. abs. pressure)										Lower Heating Value, B.T.U. per Cu.Ft.	Higher Heating Value, B.T.U. per Cu.Ft.	Remarks
	Quantity, Cu. Ft.	Chemical Analysis (Dry)											
		CO_2	CO	CH_4	C_2H_4	C_2H_6	H_2	O_2	N_2	Total Per Cent			
Natural Gas	1	trace	.....	84.7	.....	9.4	.....	.....	1.6	100	935	1132	Average composition, 25 states $C_3H_8 = 3.0\%$. $C_4H_{10} = 1.3\%$
By-product coke oven gas	1	0.75	6.00	28.15	.....	.....	53.0	.....	12.1	100	428 *	478	Water vapor, 1.85% by vol.
Raw producer gas	1	7.5	20.5	3.0	.....	.....	12.5	.....	56.5	100	138.7	147.8	From Pittsburgh coal. Tar vapor, 0.000625 lb. cu. ft.
Clean producer gas	1	9.71	19.03	2.78	0.19	.....	13.48	0.02	54.79	100	128	137	
Blast furnace gas	1	12.5	25.4	.....	.....	.....	3.5	.....	58.6	100	91.8	93.5	Water vapor, 1.45% by vol.
Blue water gas	1	3.5	43.5	0.7	.....	.....	47.3	0.6	4.4	100	279	303	
Illuminating gas (coal gas)	1	4.6	5.5	36.6	4.6	.....	42.3	4.6	1.8	100	539.9	597	
Illuminating gas (carbureted water gas)	1	2.9	18.2	23.9	8.1	.....	38.3	4.8	3.8	100	506.3	533.2	
Mixed gas	1	3.46	13.84	28.3	6.92	.....	39.6	4.73	3.15	100	518.3	568.8	1 part coal gas 2 parts carbureted water gas
	Composition, Per Cent by Weight												
	Quantity, Lb.	C	H_2	O_2	N_2	S	H_2O	Ash		Total Per Cent	B.T.U. per Lb.	B.T.U. per Lb.	
Coal	1	79.86	5.02	4.27	1.86	1.18	....	7.81	.....	100	14,080	14,490	
Coal	1	70.00	5.00	8.00	2.00	2.00	.....	13.00	.....	100	12,410	12,780	
Lignite (dry)	1	59.9	4.37	18.64	1.22	2.65	.....	13.22	.....	100	9,897	10,082	Average composition
Lignite (wet)	1	41.93	3.06	13.05	0.85	1.86	30.0	9.25	....	100	6,917	7,063	
Coal tar	1	86.7	6.0	3.10	0.116	0.745	3.20	0.097	.....	99.958	15,827	16,341	
Fuel oil	1	84.0	12.7	1.2	1.7	0.400	..	....	.....	100	18,830	19,980	

Higher heating value = Lower heating value plus latent heat of water vapor produced by the combustion.
* Heating value is low because care was not taken to keep down the nitrogen content.

Fuel	Perfect Combustion with Theoretical Air: Requires Lb. per Cu. Ft. of Gas: O_2	N_2	Air	Products of Perfect Combustion, Lb. per Cu. Ft. of Gas: CO_2	H_2O	N_2	Total	Heat Content of Products of Perfect Combustion of 1 Cu. Ft. of Gas	Flame Temp. Degree Fahr.	Specific Volume of Products 62° F. 14.7 lb. per sq. in. abs. press.
Natural gas	0.1895	0.6290	0.8185	0.1365	0.1026	0.6302	0.869	$0.2230(t-62)+0.0000188(t^2-62^2)$	3610	13.63
By-product coke oven gas	0.0725	0.2415	0.314	0.0406	0.0519	0.2510	0.3435	$0.0910(t-62)+0.00000785(t^2-62^2)$	3590	14.06
Raw producer gas	0.0207	0.0690	0.0897	0.0379	0.0092	0.1104	0.1575	$0.0380(t-62)+0.00000318(t^2-62^2)$	2970†	
Clean producer gas	0.0190	0.0633	0.0823	0.0370	0.0095	0.0962	0.1427	$0.03454(t-62)+0.00000300(t^2-62^2)$	3000	12.85 (10% excess air)
Blast furnace gas	0.0121	0.0403	0.0524	0.0440	0.0017	0.0835	0.1292	$0.02943(t-62)+0.00000256(t^2-62^2)$	2590	12.10
Blue water gas	0.0389	0.1300	0.1689	0.0550	0.0232	0.1331	0.2113	$0.05288(t-62)+0.00000494(t^2-62^2)$	3910	13.12
Illuminating gas (coal gas)	0.0895	0.2975	0.387	0.0648	0.0592	0.2985	0.4225	$0.1103(t-62)+0.00000962(t^2-62^2)$	3740	
Illuminating gas (carbureted water gas)	0.0815	0.2705	0.352	0.0715	0.0491	0.2730	0.3936	$0.1011(t-62)+0.00000888(t^2-62^2)$	3810	
Mixed gas	0.0838	0.2782	0.362	0.0689	0.0521	0.2810	0.4020	$0.1036(t-62)+0.00000909(t^2-62^2)$	3800	13.67

	O_2 Lb. per Lb.	N_2 Lbs. per Lb.	Air Lbs. per Lb.	CO_2	H_2O	N_2	Total Lbs. per Lb.	Heat Content of Products of Perfect Combustion of 1 Lb. of Fuel		
Coal	2.505	8.295	10.8	2.953	0.452	8.318	11.723	$2.779(t-62)+0.000227(t^2-62^2)$	3920	40% excess air 12.78
Coal	2.21	7.32	9.53	2.61	0.45	7.34	10.400	$2.470(t-62)+0.000203(t^2-62^2)$	3860	
Lignite (dry)	1.788	5.932	7.72	2.25	0.3933	5.0445	8.5878	$2.045(t-62)+0.000171(t^2-62^2)$	3740	
Lignite (wet)	1.251	4.154	5.405	1.575	0.5755	4.1625	6.3125	$1.561(t-62)+0.00014(t^2-62^2)$	3430	
Coal tar	2.79	9.26	12.05	3.18	0.572	9.30	13.052	$3.11(t-62)+0.0000254(t^2-62^2)$	3920	20% excess air 12.95
Fuel oil	3.26	10.77	14.03	3.088	1.143	10.8	15.031	$3.704(t-62)+0.000307(t^2-62^2)$	3900	20% excess air 13.14

t = temperature of the products of combustion, degrees F. The figure 62 appears in the expressions for heat content because 62° F. is taken as the basis of calculation. Heat content is that *above* 62° F.

* See also Figs. 1 to 10. † This value is meaningless and is given only for the sake of completeness. Actually, raw producer gas is never burned cold.

The theoretical flame temperatures corresponding to different conditions are shown in the curve sheets, Figs. 1 to 10. It should be noted that, in calculating these curves, the effect of dissociation of part of the products of combustion was neglected.

The following table shows the percentage of dissociation

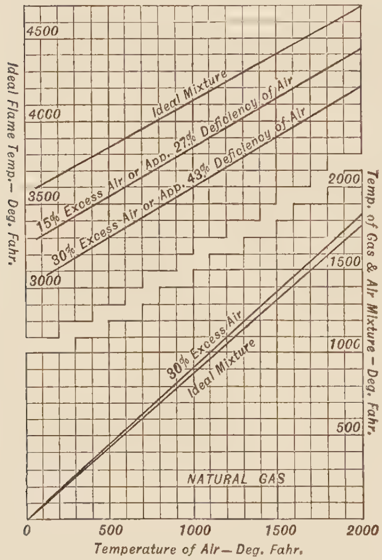


Fig. 1.—Ideal flame temperatures of natural gas, with air preheated to various temperatures.

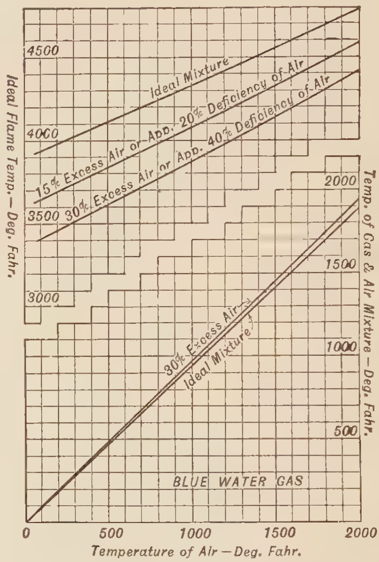


Fig. 2.—Ideal flame temperatures of blue water gas, with air preheated to various temperatures.

of CO_2 in a mixture of 21 per cent CO_2, 79 per cent N_2 by volume:[1]

TABLE II

Temperature Degrees F.	Per Cent Dissociation of CO_2
2250	0.07
2500	0.24
2750	0.70
3000	1.65

[1] The values given in the table were obtained from Schuele's "Technische Thermodynamik," and were also checked by calculations from "Bulletin No. 139 of the Engineering Experiment Station, University of Illinois," by Goodenough and Felbeck.

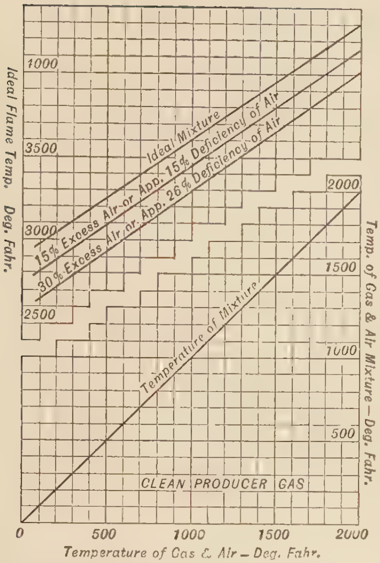


FIG. 3.—Ideal flame temperatures of clean producer gas, when both gas and air are preheated.

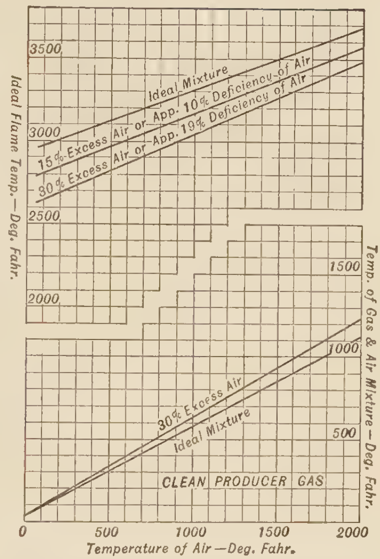


FIG. 4.—Ideal flame temperatures of clean producer gas, when air only is preheated.

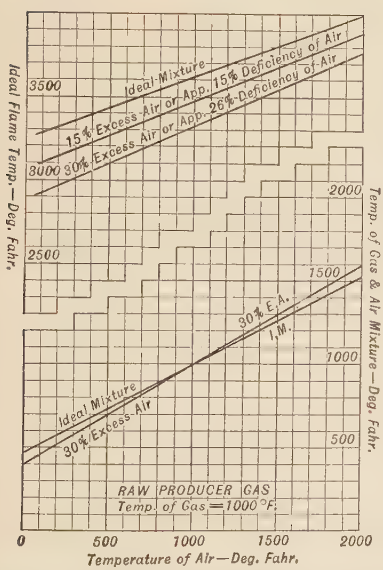


FIG. 5.—Ideal flame temperatures of raw producer gas; gas initially at 1000° F., air preheated to various temperatures.

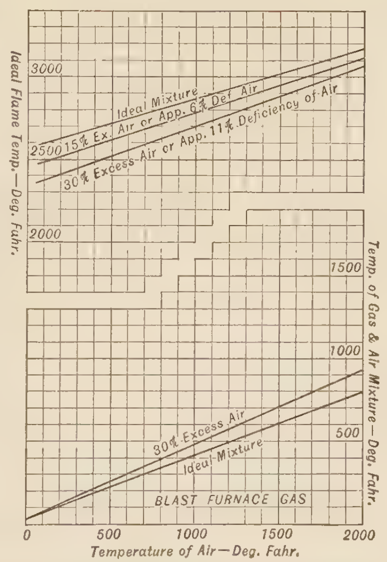


FIG. 6.—Ideal flame temperatures of blast-furnace gas, with air preheated to various temperatures.

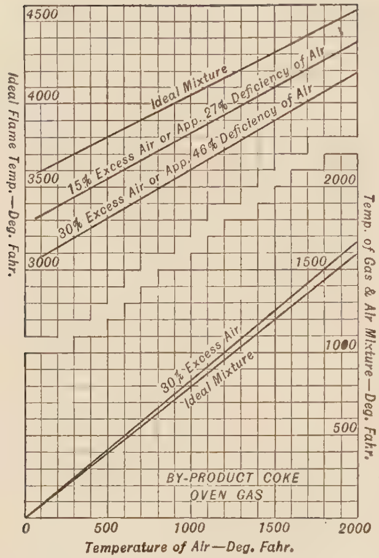


FIG. 7.—Ideal flame temperatures of coke-oven gas, with air preheated to various temperatures.

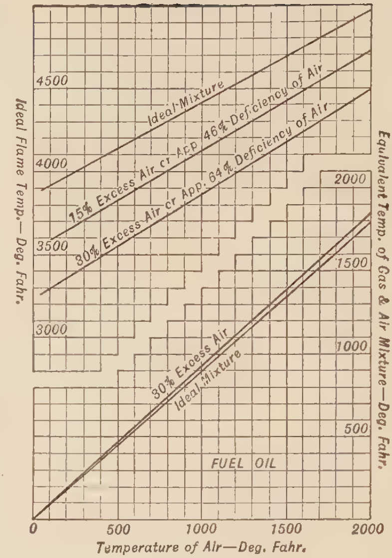


FIG. 8.—Ideal flame temperatures of fuel oil, with air preheated to various temperatures.

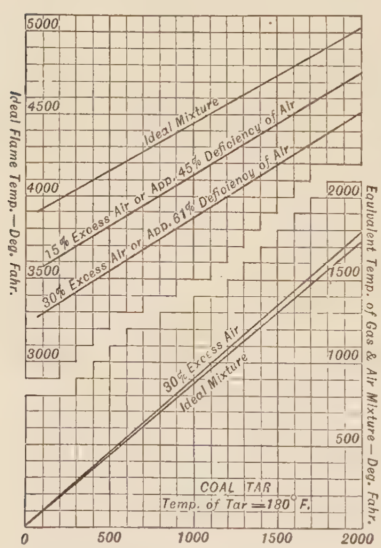


FIG. 9.—Ideal flame temperatures of coal tar, with air preheated to various temperatures.

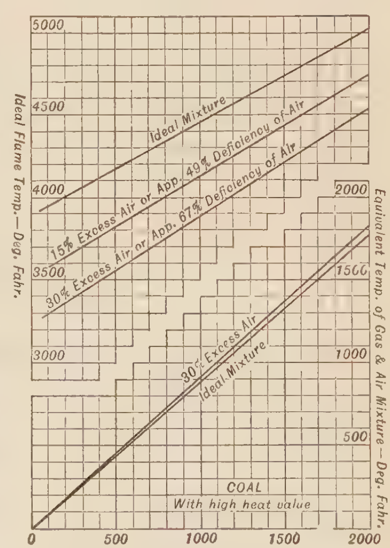


FIG. 10.—Ideal flame temperatures of coal, with air preheated to various temperatures.

It is evident that the effect of dissociation is negligible for the temperatures encountered in industrial heating furnaces. It assumes importance in high-temperature melting furnaces, but these are not considered in the present volume.

The flame temperatures which are attained in practice depend upon speed of combustion and upon heat abstraction during combustion. The actual temperature-rise lies between the values of 48 per cent and 75 per cent of the theoretical temperature increase. Combustion will have to be extremely slow to depress the temperature-rise below 48 per cent of the theoretical, and extraordinarily favorable conditions are required to make the temperature-rise exceed 75 per cent of the theoretical value.

Combustion practically never occurs with the correct quantity of air. Almost invariably there is either an excess or a deficiency of air. Even if the correct quantity of air is used, there will be a deficiency of air in some parts of the combustion space unless the mixing of fuel and air is very thorough. The combustion conditions which exist with a given fuel and a given combustion device are discussed under the heading of that fuel and combustion device.

GASEOUS FUELS

Of the three types of fuels (gaseous, liquid, and solid), gases offer the greatest number of advantages. They are easily transported to any number of furnaces. Most of them can be burned without smoke, even in a cold furnace. They can be mixed with air in proper proportion without previous preparation; they allow easy control of temperature, of furnace atmosphere and of temperature distribution.

Natural Gas.—This gas is a most desirable fuel wherever it can be secured at a reasonable price. Its high heating value allows transportation through small pipes. It is clean and free from sulphur. Its use causes no stand-by losses, because the earth acts as a reservoir. Unfortunately, natural gas is becoming scarce in many industrial districts and is frequently withdrawn from industrial use during the winter months, so that it may serve as domestic fuel. In other districts, the gas supply is maintained, but the gas is diluted with water gas and cold producer gas, both of which have heating values lower than that of natural gas. This practice results in the delivery of a gas of

variable heating value, and makes continuously perfect combustion with the correct quantity of air almost impossible.

Natural gas coming directly from wells occasionally contains gasoline vapor, and in that case has a higher heating value than the one given in the tabulation.

Natural gas contains enough carbon to produce luminosity of flame if cold air is used, and only a moderate degree of pre-mixing of gas and air is practiced. The carbon content prevents its being preheated to any extent in regenerators or recuperators because the hydrocarbons break up at high temperatures. Moreover, the gain would be very small, because the weight of the gas is less than one-fifteenth of that of the combined fuel and air mixture. The cost of natural gas in 1923 (with common labor at 30 cents an hour and pig iron at $27 per ton) lay between 15 and 60 cents per 1000 cubic feet. The wide range was caused principally by unequal distances from producing wells. In most sections where natural gas has been available, its cost is rising rapidly and steadily.

Coke-oven Gas.—This gas is produced by high-temperature distillation of bituminous coal or of a mixture of bituminous and semi-bituminous coals. As a rule, this most excellent fuel is not available to the general public, because it is made in coking plants which are adjuncts to steel works and because the latter have use for more gas than the coke works produce. Its use is therefore limited to furnaces in steel works. There are a few exceptions to this rule, but their number is exceedingly small. The following data on coke-oven gas are of interest to the user: One pound of straight, high-volatile coal furnishes 3300 B.t.u. in the total volume of by-product gas. From 1100 to 1250 B.t.u. are required to coke one pound of coal, while 200 B.t.u. are contained in the benzol which is extracted from the gas. This leaves roughly 1900 B.t.u. in the surplus gas which is made from one pound of coal. With excellent regenerative efficiency and capable oven supervision, the latter value can be raised to 2000 B.t.u. on straight, high-volatile coal. In the case of low-volatile coals, such as those coming from the Pocahontas and Somerset fields, the calorific content of the gas drops down to 2500 B.t.u. per pound of coal, while the heat demand for coking remains constant, namely, 1200 B.t.u. per pound of coal; on the other hand, only 100 B.t.u. go into the benzol, so that 1200 B.t.u.

are available in the surplus gas from each pound of coal. From these figures, the amount of heat available from a pound of mixed coal can be computed for any mixture.

The information contained in these data is probably more reliable than any figure giving the amount of surplus gas, because leaks into or out of the system will affect the quantity of surplus gas. However, some engineers prefer the information in that shape, and for them the following data will be of interest. One short ton of straight, high-volatile (Pittsburgh) coal produces from 6300 to 6400 cubic feet of surplus gas.

The heating value of coke-oven gas made from Pittsburgh coal averages about 565 B.t.u. per cubic foot (higher heating value, at 62° F., 30 inches barometer). The corresponding value for mixed coal is about 540 B.t.u. Both figures apply to debenzolized gas. Typical analyses of the gas are as follows:

	CO_2	C_2H_4	O_2	CO	H_2	CH_4	N_2	Sp.Gr.
Straight Gas								
Before removing benzol...	2.2	3.5	0.3	6.8	47.3	33.9	6.0	0.44
After removing benzol....	2.2	2.6	0.3	6.9	47.3	34.2	6.0	0.42
Lean Gas								
Before removing benzol...	2.1	2.0	0.3	6.0	57.0	27.0	5.6	0.38
After removing benzol....	2.1	1.0	0.3	6.1	57.5	27.3	5.7	0.35

A somewhat different analysis of coke-oven gas is given in Table I. The composition varies considerably with the kind of coal, time and temperature of coking, air infiltration, and other factors; no analysis can apply to all conditions. Wherever possible, the composition of the particular gas to be dealt with should be ascertained by test.

The low value of the specific gravity of coke-oven gas (averaging about 0.39 referred to air) is due to the high content of hydrogen and methane. On that account also, the lower heating value is comparatively low; for the "straight gas" given above, it is about 508 B.t.u. per cubic foot. The presence of a small percentage of illuminants insures a luminous flame, unless the gas is thoroughly mixed with the air before combustion begins. To complete the statement of the properties of by-product coke-oven gas, it should be mentioned that each 100 cubic feet of gas contain 350 grains of hydrogen sulphide and 15 grains of carbon disulphide.

The cost of 1,000,000 B.t.u. is of importance with coke-oven gas, as with other fuels. But in arriving at the cost a great

difficulty arises, because the gas is usually considered as a by-product and, for that reason, "costs nothing." It has been said that by-product coke plants can afford to give their gas away, and earn money from the sale of coke, benzol, tar, and ammonium sulphate. Yet the gas has a value which is, however, more or less arbitrary, as long as the coke plant sells gas to the steel plant under the same management. At 1919 prices of coal and labor one steel plant valued the gas at 5 cents per 1000 cubic feet, while two other plants valued it at 7 and 10 cents, respectively. These low values are not maintained in coke plants which sell gas and coke for domestic use, because in such plants coke is the by-product, and because domestic coke is worth less than metallurgical coke. In these plants, the gas is valued at from 25 to 35 cents per 1000 cubic feet. This price holds for coal at $2.50 per ton at plant. It changes almost $\frac{1}{2}$ cent per 1000 cubic feet for every 10 cents change in the cost of coal.

In judging the quantity of coke-oven gas which is available in a given steel plant we must not lose sight of the amount which must be sacrificed for purposes of regulation. At one time or another the supply of fuel to a furnace must temporarily be increased above the average value, and there must be a place from which it can be diverted. As a rule, that place is at the boiler plant, where 6 to 8 per cent of the coke-oven gas is burned regularly. If the demand for gas at the furnaces is increased, less gas goes to the boilers. The deficiency at the boilers is made up by burning more coal.

Water Gas.—Water gas is generated when steam is blown through glowing carbon. At low temperatures (about 930° F.) carbon dioxide and hydrogen are formed, while at high temperatures (1600° F. or above) carbon monoxide and hydrogen are formed. Between the two temperatures (930° to 1600° F.) carbon monoxide, carbon dioxide, and hydrogen are formed. Either of these processes abstracts heat from the fuel bed and lowers its temperature. If the latter is allowed to drop too much, water vapor, in addition to the above-mentioned gases, will pass into the water gas.

At the present time no process exists to make water gas continuously in the same producer or generator, because the breaking up of the steam into hydrogen and oxygen requires more heat than is given off by the combination of the carbon and

the oxygen. As previously mentioned, the temperature of the fuel bed drops off continuously while water gas is being made, because no method is known of imparting heat to the bed of glowing carbon while the heat is being abstracted from it by the formation of water gas. For this reason the process must be intermittent; the fuel is heated to a high incandescence by an air blast, and then the steam is passed through the same generator, until the temperature has been reduced almost to the point below which good gas can no longer be obtained. The process thus calls for alternate " blows " with air and " runs " (gas-making periods) with steam.

The intermittent feature of the gas-making process necessitates either the use of two generators with a small gas holder, or else the use of one generator with a large gas holder. If, in the latter case, the gas is to be used at the average rate at which it is made, the capacity of the holder need not exceed the volume produced during an hour's production.

In either case (one or two generators) the producer works on a constantly falling temperature during the run. For that reason, the composition of the water gas varies. Inasmuch as it is now an easy matter to make water gas with carbon dioxide content not greater than 3.5 per cent, this fact is of theoretical interest only. The necessarily frequent reversals of valves would permit some blast gases to become mixed with the water gas, if the valves of the generator were operated by hand. Formerly that was done, and an average cycle of operations consisted of two minutes for blasting and four minutes for steaming. Water gas sets are now operated automatically, however, and by this development the human element is eliminated. The automatic control is capable of such fine adjustment that shorter cycles can be obtained. The result is a saving of fuel, an increased output of more uniform gas, and the formation of clinker of such a nature that it can be very quickly removed. By means of vernier adjustments in the mechanism the operation is so timed that the blast gases are practically all swept from the apparatus into the stack by the water gas, which is shunted at the right instant into the system. The automatic control permits the maintenance of an almost uniform temperature in the active zone.

Both the air gas made during the blow and the water gas made during the run contain a great deal of sensible heat which,

if not utilized, would necessarily result in a very low efficiency of the generating process. By using this heat for raising steam for the run, the efficiency is brought up to a much higher value. Water-gas apparatus with a waste-heat boiler has an efficiency of approximately 70 per cent, provided that it is carefully designed and skillfully operated and that clean fuel is used. Otherwise, the efficiency will easily drop down to 50 or 55 per cent.

One of the drawbacks of water gas is that it can ordinarily be generated only from coke or anthracite. There are a few instances of the use of bituminous coal, and this development has great promise. Much credit is due to the activities of the Bureau of Mines in this case. The blue water gas is generally desired for use as a cold, clean gas for high-temperature work. Hence, from the apparatus in which it is made, it is passed through a seal pot, a shower scrubber, and, if the demands are particularly exacting, it is rendered free from sulphur, in the form of hydrogen sulphide, by standard means.

Blue water gas is practically free from hydrocarbons; hence its flame is non-luminous and has a blue color due to the carbon monoxide which it contains. The term blue water gas is generally used to distinguish it from carbureted water gas, which is made by vaporization of oil in an atmosphere of blue water gas.

Blue gas is the richest industrial gas in point of intensity of combustion. (Acetylene and similar gases are not considered here, because they are not used on a large scale.) The reaction temperature, or so-called flame temperature, is the highest for any standard industrial gas known. Owing to the absence of hydrocarbons already referred to, it is impossible for smoke to be produced with the use of blue water gas. A special and time-honored use for the gas is in the welding of steel tubes, tanks, stills, etc., having a thickness of more than $\frac{3}{8}$ inch. It is also used for melting glass, heat treating, carburizing and annealing steel, and for general factory purposes.

The cost of blue water gas depends upon the price of the fuel to be used, the cost of labor per hour, the quality of gas desired, the existing facilities which can be utilized in the installation, and the size of the installation. Unfortunately, no fair opinion as to its cost in a specific case can be arrived at through the consideration of these items, except by those who furnish equipment for making the gas. The following data, however,

may be of use: Good coke is generally rated to produce 50,000 cubic feet of 300 B.t.u. gas per net ton, or 15,000,000 B.t.u. per net ton: When waste-heat boilers are employed, there is a considerable saving due to the steam, which is made in sufficient quantity to answer every requirement of the operation. For every net ton of coke. 2000 to 2200 pounds of steam are needed.

On the basis of labor at 40 cents per hour the interest on the investment is equivalent to 13 cents per million B.t.u. in small plants and to 8.5 cents per million B.t.u. in large plants. The labor cost of gasifying a ton of coke varies between 70 cents and one dollar, with labor at 40 cents per hour.

From the above data it follows that water gas is not at all suitable for a plant having one or two small furnaces, because the investment cost and the cost of the gas-house equipment are prohibitive. The larger the furnace plant, the better the installation of water-gas equipment pays. If heating for forging, rolling or annealing is the only requirement, clean producer gas is just as good and is preferred by many.

For furnaces with variable or intermittent demand for heat it is quite difficult to regulate the gas generation to coincide with the widely fluctuating demand, and thus maintain the right gas pressure.

Blue water gas burns without flame and, for that reason, gives off very little heat by radiation. In consequence it appears logical to provide, in furnaces with water gas firing, flame-swept refractory surfaces which are large in comparison to the surface of the charge or stock, or else, in the absence of enlarged surfaces, to figure with a lower coefficient of heat transmission. In many types of furnaces the refractory surfaces which are washed by the products of combustion are large enough in any event because of the space which has been allowed for flame development. In such cases there is no need of any difference in design between furnaces intended for the use of water gas and those for gases which burn with a luminous flame.

City Gas.—In many cities where natural gas is not available, artificial gas is used in industrial furnaces. This gas, often referred to as "city gas" or "town gas," may be one of several gases; coal gas, also called retort gas; water gas; oil gas; or a combination of any two or all of them. A combination of water

gas and oil gas constitutes carbureted water gas. The mixture which is most commonly distributed through the gas mains of our large cities consists of carbureted water gas and coal gas. In some municipal plants these gases are not mixed but are sent through the mains separately.

Coal gas is made by the destructive distillation, or "carbonization," of coal in externally heated ovens or retorts. Bituminous coal is used in this process, and the resulting by-products are coke, retort carbon, tar, and ammoniacal liquor. One short ton of coal yields an approximate average of 10,000 to 11,000 cubic feet of gas and between 1200 and 1300 pounds of coke. The calorific value of this gas is in the neighborhood of 600 B.t.u. per cubic foot. The gas produced requires purification and is, therefore, passed through scrubbers to take out any solid matter which may be present.

To form carbureted water gas, oil gas is added to the water gas (the process of making the latter has already been described). This is done in a continuous process in the following manner: While the carbon is being brought up to an incandescent state by means of an air blast, the hot products of combustion passing off are admitted into a brick checker chamber (carburetor), and thence to another chamber known as a superheater. When the carburetor and superheater are heated up to the desired temperature, the air blast is shut off and the stack valve over the superheater is closed. Steam is blown through the coal bed as previously described (in the process of making water gas), forming blue water gas, which passes over into the carburetor and superheater. Oil is sprayed in at the top of the carburetor. When it comes in contact with the hot bricks of the carburetor and the superheater, it breaks up into gases. After leaving the superheater the gas is bubbled through water to remove any soot and tar which may be present. It then passes through coolers to the storage tanks. The gas thus formed has a calorific value of approximately 550 B.t.u. per cubic foot.

An average chemical composition and the ideal flame temperatures of coal gas, carbureted water gas, and a one-to-two mixture of the two are shown in Table I. The cost of city gas in various localities ranges at the present time (1925) from \$.75 to \$3 per 1000 cubic feet, with an average for the whole country of about \$1.22 per 1000.

Producer Gas.—In the present-day meaning of the term, producer gas is that gas which is obtained by blowing a mixture of steam and air through a deep bed of glowing carbon. If air alone is blown through the coal, air gas is made. Variations in the air-steam ratio produce variations in the composition of the gas. The latter also varies with the kind of coal which is used, because the making of producer gas involves three steps, namely, drying (giving off water vapor), distillation of volatile matter, and gasification of carbon. Evidently, gas made from coke or anthracite will contain none of the distillation products of coal, while gas made from bituminous coal will contain a great variety of hydrocarbons.

These hydrocarbons are broken up to a greater or lesser degree, depending upon the temperature at the top of the producer. With little steam in the blast, with a shallow fuel bed, or channels or flues in the fuel bed, the producer runs hot and makes much CO_2, and the volatile matter is broken up into hydrogen and soot. The result is a poor, hot gas with much CO_2 and H_2 and little CO, and a clogging of the gas main with soot.

Raw Producer Gas.—The gas coming directly from the producer is called raw producer gas. It is quite commonly burned in furnaces without any cleaning or cooling. In that case, producer and furnace (or furnaces) should be placed as close together as possible in order to utilize the sensible heat in the gas and the calorific value (combustion heat) of the uncondensed tarry vapors. The gas flues between producer and furnace are brick-lined. They fill up with soot [2] and some tar and must be burned out at regular intervals. Although this work involves some inconvenience, by far the greatest number of producer-gas-fired furnaces burn raw gas.

It is difficult to measure the flow of raw producer gas because of the clogging action of soot and tar. Regulation of the rate of gas generation involves regulation of the steam and air flow, of the rate of feeding coal, and, to a certain extent, of the rate of ash removal. At the time of writing this chapter no apparatus exists for regulating these various quantities so as to automatically maintain a constant quality of gas in the face of a variable demand for gas. It is true that there are devices which maintain a constant

[2] This action may be caused, in part, by the unstable condition of CO at high temperatures; it breaks up into CO_2+C, which is soot.

gas pressure. They act by allowing the gas pressure to control the quantity of steam flowing through the steam-air injector. These devices do only part of the work of regulating, leaving most of it to the gas-house crew. The absence of automatic regulating devices places a serious limitation on the use of raw producer gas for furnaces with fluctuating demand for gas, particularly if constant gas pressure and constant heating value of the gas are required.

Most gas producers are cleaned at least once a day, to remove clinkers which have built up on the walls. During the time of cleaning, a very poor gas is made. In addition to cleaning, other causes contribute to variations in the composition and heat value of the gas, particularly in small, hand-poked producers (which are sometimes referred to as "smoke producers," by the attendants). These causes are: depth of fuel bed, depth of ash bed, rate of feeding fuel, steam-to-air ratio, formation and location of clinkers, wetness of coal. Usually the calorific value varies to the extent of 20 per cent in a day and 40 per cent in a week. This variableness has a detrimental effect upon furnace operation. It is utterly futile to purchase and install high-class burners which are intended to maintain a neutral furnace atmosphere, if the heating value and the composition of the gas change continually. If the latter is the case, the responsibility for correct combustion rests with the heater and with the gas maker, which means that correct combustion is very seldom obtained. Usually, the heating furnace and its appliances are blamed for the shortcomings of the producer and of its regulating devices. Measuring devices, such as a continuous calorimeter or a CO_2 and H_2 recorder, are great helps to the gas maker; but they can be used in large plants only, because they require continued attention by an experienced instrument man. A pyrometer in the top of the producer is a good guide for the operation.

In recent years much progress has been made in producer design, including mechanical charging and spreading of coal, correct agitation of the fire bed, and mechanical ash removal. All of this has contributed to furnishing a steady stream of gas of constant quality, but it has not yet solved the problem of furnishing a supply of good gas for intermittent demand.

A large part of the sulphur contained in the coal passes into the producer gas. If the gas is to serve for heating material that

is likely to be injured by sulphurous gases, great care must be taken in the selection of the coal. Frequently, the "fines" contain more sulphur than the lumps. For that reason, and also because fines reduce the capacity of a producer, screening of the coal is desirable.

The heating value of raw producer gas is low compared to that of the other fuels. The lower heating value of raw producer gas ranges between 120 and 160 B.t.u. per cubic foot (at 62° F. and 30 inches of mercury), varying with the coal from which the gas was made, the design of the producer, and most of all, with the skill and zeal of the operator. As a rule, the heating value determined from a gas analysis does not include that of the tarry constituents which are condensed before the analysis is made. Neither does it include the sensible heat of the gas. Gas made from bituminous coal carries in suspension about 0.000625 pound of tar per cubic foot. The tar not only increases the heating value but also gives luminosity to the flame.

The cost of producer gas per unit of heat is naturally of the greatest importance. It depends upon the cost and the heating value of the coal delivered, the producer efficiency, the first cost and the rate of depreciation, the load factor, and the labor connected with the gasification. The distance between the furnace and the producer affects the heating value at the furnace. The usual way of computing the cost of producer gas is as follows: Figure the heat in the gas from that of the coal, using an efficiency factor, and add the cost of gasification. Producer efficiencies range from 55 per cent (small producers, poor design, poor operation, poor coal) to 85 per cent (large producers, good coal, good design, good operation).

Example. If one ton of coal costs \$4.00, if coal contains 13,800 B.t.u. per pound, and if the producer efficiency is 75 per cent, then the cost of 1,000,000 B.t.u. (due to the cost of coal) equals $\frac{1,000,000 \times 400}{13,800 \times 0.75 \times 2000} = 19.3$ cents. The cost of gasification, including all labor, overhead, maintenance, and cost of steam, is usually expressed in dollars per ton of coal gasified. With labor at 32 to 36 cents per hour, the cost of gasification lies between 80 cents and \$2.00 per ton. An average figure is \$1.25 per ton. This cost is simply added to the cost of the coal. If an average figure of \$1.25 is used, the cost of the above-considered gas per 1,000,000 B.t.u. would be brought up to 26 cents.

Judgment and knowledge of the conditions of each individual

case are necessary to foretell correctly the cost of gasification; but, in general, it is lowest in large plants containing many large producers in continuous use, and is highest with small, individual producers, particularly if the demand for gas is intermittent. To what extent the cost of gasification per ton of coal is affected by the design and size of the producer may be judged from the fact that the rate of gasification per square foot of producer cross-section per hour, under favorable conditions, has lately been raised to 50 pounds of coal, whereas 15 pounds was considered the limit during a long period of years. For details, see "Gas Producers and Producer Gas," by V. Windett, in the January, 1923, number of the *Blast Furnace and Steel Plant.*

Clean Producer Gas.—Raw producer gas leaves the producer at a temperature between 1000° and 1400° F.; it cannot be transported through long pipe lines without losing its sensible heat and having its tarry vapors condensed. If it is necessary to locate the producer plant at a great distance from the furnace, or if many comparatively small and scattered furnaces are to be fed, the gas is cooled and cleaned. It is then known as (cold) clean producer gas. The outfit for making such gas is more complicated than the equipment used for making raw gas, consisting, as a rule, of gas producer, cooler, tar extractor, scrubber, and gas exhauster (driven by engine or motor). Clean producer gas has lost its sensible heat above that corresponding to atmospheric temperature, and can be transmitted through ordinary (not lined) steel or iron pipe. The low heating value of the gas (128 B.t.u. per cubic foot, lower value at 62° F.) necessitates rather large pipes, or else excessive power consumption for the pumpage if the gas is to be transmitted several thousand feet. Clean producer gas can be stored in gas holders, a fact which makes its use desirable for intermittent demand. Without a gas holder, it offers the same difficulties for intermittent demand as raw producer gas. For plants with numerous scattered furnaces, clean producer gas offers, in many localities, the best solution of the fuel problem.

The thermal efficiency of the clean producer process is somewhat lower than that of the process for raw producer gas (because the gas loses its sensible heat in the cleaning process) unless the heat in the gas is utilized for the generation of steam.

The gasifying charge is much higher for clean gas than it is for

raw gas. The investment is greater; the steam consumption is higher, because the gas must be forced through a cleaner; the labor charge is higher, because more equipment must be tended. With labor at 36 cents per hour, the gasifying charge per ton of coal, including interest, depreciation, producer labor, fuel for steam, coal and ash handling, boiler-house labor, and pumping ranges from $2 to $2.60.

If clean gas is preheated in a regenerative or recuperative furnace, the efficiency of preheat is greater than it is with raw gas, because the latter is hot, and because the outgoing flue gases cannot be cooled below the temperature of the incoming fuel gas.

Clean, cold producer gas burns with a clear blue flame, giving the furnace a transparent atmosphere. Even when working with a reducing atmosphere, the furnace does not smoke.

Blast-furnace Gas.—This gas is given off at the top of blast furnaces; it is available for heating furnaces in combined blast furnace and steel plants only. Its calorific value varies with the coke-to-iron ratio in the blast furnace. As a rule, the fuel practice in American steel plants is so wasteful that no blast-furnace gas is left over for use in heating furnaces; but where this gas has been used, good results have been obtained. A mixture of blast-furnace gas and by-product coke-oven gas is a very desirable furnace fuel.

Blast-furnace gas is in many respects similar to cold, clean producer gas. Its use requires an extensive gas-cleaning system, large pipe lines, and a booster. The pipe lines must be even larger than those for producer gas (on the basis of a given heat delivery in unit time), because the gas is leaner. Blast-furnace gas is extremely poisonous.

If this gas is to be used in heating furnaces for steel, in which a temperature in excess of 2250° F. is to prevail, very efficient preheating devices for both gas and air must be used.

Oil Gas.—Certain fuel oils can be vaporized without the formation of objectionable tar and soot. The vapor is occasionally called "oil gas," but it is not a fixed gas. Several processes have been tried for the generation of a true oil gas. In most of them, highly heated oil vapor is mixed with water vapor. The resulting chemical reaction produces a fixed "oil gas" and tar. For large furnaces the vaporization and combustion of oil directly

in the furnace is simpler than the detour over the oil gas producer. For small furnaces, a "gasifier," which has recently been introduced, can be recommended. It gasifies and vaporizes the oil by combustion of 3 to 5 per cent of that fuel. The device, which is of the size of an ordinary alarm clock, delivers a hot mixture of gas and vapor to the furnace, where the mixture burns exactly like city gas or natural gas.

LIQUID FUELS

The liquid fuels which are commonly used for industrial furnaces are fuel oil and tar. Gasoline, kerosene, and alcohol are too expensive to be considered for industrial purposes.

Liquid fuels offer a number of advantages. A liquid can readily be stored above or below ground, and in out-of-the-way places. Some of the liquid fuels need no preheating and are always ready to serve, like natural gas or city gas, with the additional advantage that, while natural gas is frequently shut off in cold weather, liquid fuel can be drawn from storage in the coldest of weather. With liquid fuel, there are none of the stand-by losses which are inevitable with gas producers, water gas plants, or any other equipment for the generation of an industrial gas. Temperature regulation is not affected by events beyond the control of the operator, such as occur in the gas-making processes. Liquid fuels are easily transported from storage place to furnace, and burn without leaving a residue of ash.

Liquid fuels vary in viscosity, depending upon their composition and temperature. Some of the fuels can be pumped and burned without preheating, while others need preheating. The equipment necessary for a complete installation will consequently depend upon the quality of the fuel which is to be burned.

Fuel Oil.—Fuel oils are hydrocarbons which are left after the lighter products, such as gasoline, naphtha, and kerosene, have been removed from crude oil. The composition of the fuel oil varies greatly, depending upon the origin of the crude oil and upon the degree to which the distillation has been carried. An idea of the approximate composition of fuel oils may be obtained by the study of the following tabulation:

TABLE III

Origin or description of fuel oil	Specific gravity at 62° F.	Chemical Composition				Higher calorific value B.t.u./lb.	Theoretical volume of air required per pound of oil, cubic feet at 62° F. and 30 inches barometer
		Per cent, C	Per cent, H_2	Per cent, O_2+N_2	Per cent, S		
Pennsylvania...	0.89	84.9	13.7	1.4	....	19,210	192
Texas.........	0.92	84.6	10.9	2.9	1.6	19,060	186
California.....	0.95	86.4	11.3	1.2	0.6	18,720	183
Mexico........	0.91	82.8	12.2	2.1	2.8	18,490	183
Russia........	0.88	86.0	13.0	1.0	....	19,440	191
Galicia........	0.86	85.3	12.6	2.1	....	......	187
Rumania	0.84	85.3	14.2	0.5	....	......	195
Germany......	0.94	86.0	11.0	2.0	....	......	181
Gas oil........	0.85–0.89	86.2	12.6	1.1	....	18,940	189
Masut (very heavy residue)	0.89–0.93	86.3	12.5	1.2	....	......	188

The heating value per pound varies from 17,000 to 20,600 B.t.u.; while the heating value per gallon varies from 151,000 to 134,000 B.t.u. The heavier Mexican oils have, as a rule, a smaller heating value per pound and a greater heating value per gallon than the other American oils. When the heat units per pound of oil are not known, the value may be estimated approximately by means of an empirical formula utilizing the specific gravity. This equation, which was published by Sherman and Kropff in the October, 1908, number of the *Journal of the American Chemical Society,* is as follows:

$$\text{Calorific value in B.t.u. per pound} = 18{,}650 + 40\ (\text{Baumé reading} - 10). \quad (1)$$

In the designation of a fuel oil, specific gravity plays an important part. The western and southwestern oils of the North American continent have a specific gravity of from 0.9 to 0.97 (25 to 14 degrees Baumé), while the fuel oils from eastern fields (as well as the Rumanian oils) have a specific gravity ranging from 0.80 to 0.90 (44 to 25 degrees Baumé). The viscosity of the oil (which determines the character of the heating apparatus re-

quired for its pumping and atomization) varies with the density, the light oils being more fluid at room temperature than the heavy ones. However, there is no definite connection between density and viscosity; oils of the same density, but of different origin, frequently have different viscosities. Although the latter property is of great importance for the combustion of oil, it is not readily measured, requiring a delicate instrument for its

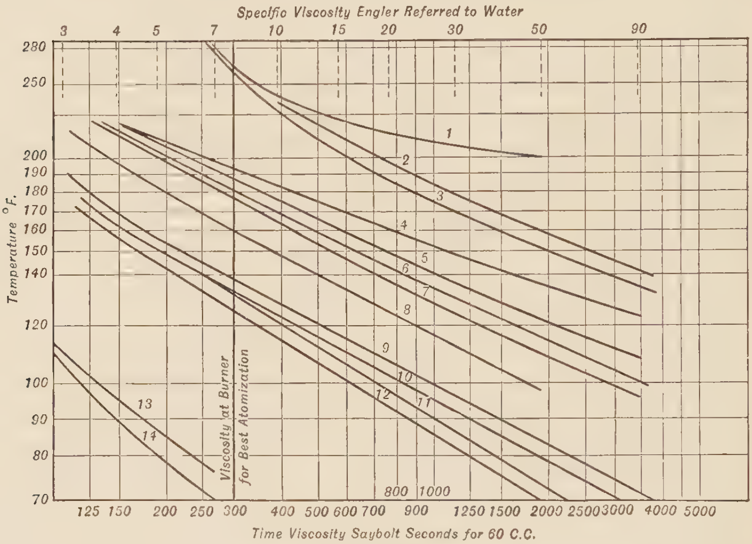


FIG. 11.—Viscosities of fuel oils at various temperatures.

(1) Mexican Residue, 10 B. 374 F. Flash (open cup). (2) "Toltec Fuel Oil," Inter-Ocean Oil Co., 11.7 B. 228 F. Flash. (3) "Toltec or Panuco Oil," Inter-Ocean Oil Co., 12 B. 124 F. Flash. (4) "No. 102," Union Oil Co., Bakersville, California, 12.9 B. 280 F. Flash. (5) "Standard" Mexican Crude, 15.4 B. 202 F. Flash. (6) "Gaviota Refinery," Associated Oil Co., California, 17.1 B. 230 F. Flash. (7) "Standard Mexican Crude," 17 B. 145 F. Flash. (8) "Nos. 1, 2, 3," Anglo-Mexican Petroleum Products Co., 15.8 B. 188 F. Flash. (9) Union Oil Co., California, 18.5 B. 223 F. Flash. (10) Richmond, California, 17.1 B. 228 F. Flash. (11) "Avon Refinery," Associated Oil Co., 17.1 B. 168 F. Flash. (12) Sun Co.'s Louisiana, 19.8 B. 275 F. Flash. (13) Gulf Refining Co.'s Navy Standard Oil, 27.5 B. 180 F. Flash. (14) Standard Illinois, 27.2 B. 146 F. Flash.

determination. On the other hand, the degrees Baumé (which express the specific gravity) can be easily measured with an hydrometer. This fact, coupled with the general, although indeterminate, relation between viscosity and specific gravity, has given rise to the general custom of describing an oil by its density rather than by its viscosity.

Since the temperature-viscosity relation is very important for fuel oils, that relation is given in the curves in Fig. 11 for

many oils used in the United States. The data were taken from tests made by the U. S. N. Fuel Testing Plant.

Oil is sold by volume rather than by weight, the unit being the barrel of 42 U. S. gallons. As the volume of a given weight of oil varies considerably with the temperature, weight deductions from the volume must be based on a definite temperature, which is usually 60° F. In the checking of quantities of oil in storage tanks, the temperature should be taken into consideration.

The cost of fuel oil varies within wide limits, both with regard to location and to time. It is usually expressed in cents per gallon. If oil costs 10 cents per gallon (prices of oil lie both above and below that figure), and if the average heating value of 144,000 B.t.u. per gallon is used for calculation purposes, then 1,000,000 B.t.u. will cost 69 cents. While this figure is much higher than the cost of the same quantity of heat for coal, oil is much used, for obvious reasons. Compare also with Chapters VI and VII.

Coal Tar.—Coal tar is one of the products of the destructive distillation of bituminous coal carried out at high temperature. A typical composition of tar follows: Carbon, 86.7 per cent; hydrogen, 6.0 per cent; nitrogen, 0.1 per cent; sulphur, 0.8 per cent; oxygen, 3.1 per cent; ash, 0.1 per cent; water, 3.2 per cent. The black color is due to free carbon in suspension (about 4 per cent). The high heating value equals 16,340 B.t.u. per pound. The viscosity is about 140 Saybolt seconds at 140° F. Coal tar weighs 9.5 pounds per gallon. It will be seen from the above analysis that the tar has almost the same chemical composition as the combustible matter of the coal from which it is made.

The relation between the viscosity of tar and its temperature is indicated by Fig. 12. Tar is very viscous when cold, and must be preheated before it can be pumped through pipe lines. It is not advisable to increase the temperature of tar to more than 165° F. or 170° F. at the maximum, for several reasons. It contains volatile constituents, which evaporate and cause irregular operation of the burners, and have a low flash point so that there would be danger of fire in case of leaks in the pipe lines. If tar is kept at a temperature of 200° F. (or above) for some time, a hard coke residue settles at the bottom of the tank.

Tar is principally used in the reheating furnaces and open-hearth furnaces of steel works. It is not easily obtainable in the

open market. Since it is a by-product, its cost price is more or less arbitrary.

Reference has already been made to the fact that tar carries suspended particles of carbon. As these are of various sizes, it is necessary to strain the tar carefully before it reaches the tar burner.

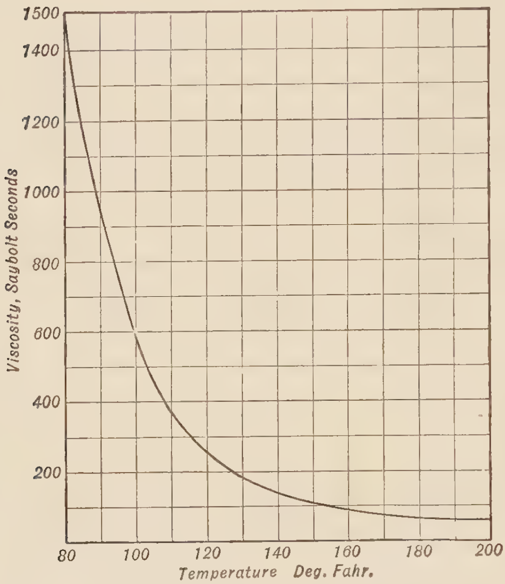


FIG. 12.—Relation between temperature and viscosity of by-product tar.

Tar Oil.—In low-temperature distillation of coal, a light-colored oil is obtained which has been given the name "tar oil." It is the starting point for many light liquids, such as benzol, toluol, and others. It forms an excellent fuel for Diesel engines, and can be burned like fuel oil in industrial furnaces. At the present time, the output of tar oil in the United States is so small that it can scarcely be considered as a fuel for industrial furnaces. This condition will doubtless be changed in the future, and when this occurs it will be advisable to investigate the properties of this fuel more carefully.

SOLID FUELS

Coal (including lignite), coke, wood, charcoal, and peat are the solid fuels which are in use in various parts of the world. Wood, charcoal, and peat practically never serve as fuel for industrial furnaces and need not be discussed here.

Solid fuels, unless used in powdered form, cause some inconvenience in transportation to the furnace, and have the additional disadvantage of leaving ashes and clinkers which must be removed from time to time.

The combustion of solid fuel on a grate cannot be as well controlled as that of gaseous or liquid fuels. If solid fuel is finely powdered the control of the combustion approaches in effectiveness that of the previously mentioned fuels, without, however, reaching it.

Coal.—Coal, is, without any doubt, the most important industrial fuel in the world. Many other fuels such as coke, tar, coke-oven gas, retort gas, water gas, producer gas, and blast-furnace gas, are derived from it. "Coal" is a collective term for a wide variety of fuels, with different properties and different heating values.

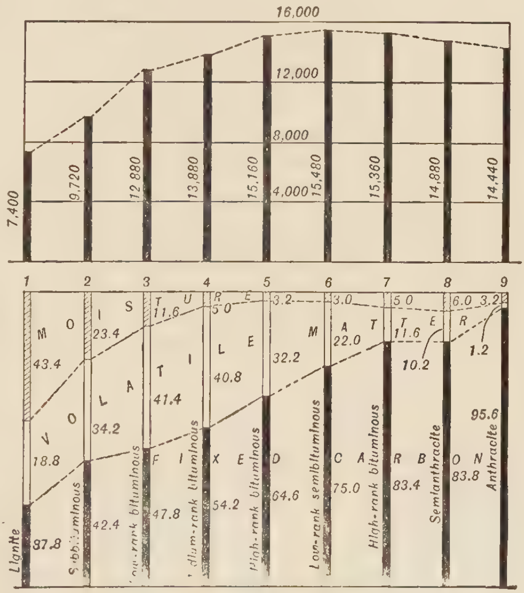


FIG. 13.—Composition and heating value of various kinds of coals.

Diagrams showing the chemical composition and heat efficiency of the several ranks of coal. Upper diagram: Comparative heat value of the samples of coal represented in the lower diagram, computed on the ash-free basis. Lower diagram: Variation in the fixed carbon, volatile matter, and moisture of coals of different ranks, from lignite to anthracite, computed on samples as received, on the ash-free basis.

Figure 13[3] gives a faint conception of this variety, and incidentally explains the relation between composition, heating value of ash-free coal, and name. In practice, still greater variation is introduced by difference in ash content and composition of the ash.

It is impossible to predict all the properties of a coal from the proximate analysis represented by Fig. 13. The chances of predicting the properties from an ultimate analysis are somewhat better, but the prediction is by no means infallible, because the hydrocarbons exist in the coal in different combinations. As definite methods of predicting the properties of a brand of coal

[3] From Prof. Paper 100–A, U. S. Geol. Survey (1917), 3; M. R. Campbell, "The Coal Fields of the United States."

do not exist at the present time, trial and experimentation are necessary.

The bituminous coals are the most important ones for industrial furnaces as well as for coking and for gasification. Anthracite is used for making water gas.

The behavior of coal on the grate, in the coke oven, and in the gas producer, depends to a very large extent upon its coking or caking properties as well as upon its chemical composition. In the United States no generally accepted simple classification exists from which these properties can be predicted. For that reason, taking an originally German classification as a basis, Table IV has been compiled to cover American coals, with the full understanding that any such tabulation, at best, can be only an approximation.

"Caking coals" are those which fuse and swell in size when heated; non-caking coals burn without fusing. In general, the high volatile coking and gas coals are caking coals, while the low volatile or semi-bituminous coals are non-caking. The caking and swelling properties of coal are believed to depend upon the content of resins. The O_2/H_2 ratio gives an indication of these properties, the caking coals being those for which this ratio lies within the limits of 1.0 and 2.0 approximately.

The quantity and composition of the ash in the coal has great influence upon the quality and the usefulness of the coal for specific purposes. That property of the ash which is of greatest importance is its fusibility. The latter varies within wide limits. Data on the fusing temperature of the ash of coals of different origin are given in Bulletins 129 and 209 of the Bureau of Mines. In cases of trouble it is advisable to send coal samples to a testing laboratory (the United States Bureau of Mines, Pittsburgh, Pa., will furnish addresses of coal-testing laboratories) and to have the fusing point determined by test. Endless annoyances with gas producers, coal grates, or powdered-coal furnaces can be prevented by regular testing of samples of delivered coal.

The brown coals, or lignites, contain a great deal of moisture, and are unsuited for use in industrial furnaces, unless the moisture is first driven off by an inexpensive process. Dried coals are very hygroscopic; that is to say, they readily re-absorb moisture from the atmosphere after having been dried. This fact should be kept in mind by all those who use them for industrial furnaces.

TABLE IV.—CLASSIFICATION OF COALS

Rank of coal	Designation, use, and combustion characteristics	Composition, "ash and moisture free," per cent by weight			Ratio $\frac{O_2}{H_2}$	"Fuel Ratio" = $\frac{\text{Fixed C.}}{\text{Volatile matter}}$	Dry Coal		Specific gravity	Coke yield, per cent	Condition of residue after distillation
		Per cent C	Per cent H_2	Per cent O_2			Volatile matter, per cent	Ash, per cent			
Sub-bituminous	Free burning, non-caking; burns with a long flame.	77 to 81	6 to 5.3	16 to 12.8	2.7 to 2.4	1.2 to 1.6	30 to 40	5 to 16	1.2 to 1.25	55 to 60 (Not used for coking)	Powder, or slightly sintered.
High-volatile bituminous	"Gas coal." Used for making illuminating gas; burns with a long flame; cakes when heated.	84 to 87	5.7 to 5.0	8.0 to 6.2	2.0 to 1.2	1.5 to 1.9	32 to 37	6 to 8 See note (1) below	1.25 to 1.4	65 to 70	Fused and fractured or fingery brittle coke.
	"Coking coal" for beehive ovens only; cakes when heated.	About 87	About 5.0	About 6.5	1.75 to 1.0	1.9 to 2.0	About 32	About 7 See note (2) below	1.25 to 1.4	65 to 70	Fused, compact, block coke.
Low-volatile bituminous, or semi-bituminous	"Steam coal." Also much used for mixing with gas coal for by-product coking; burns with a short flame, not much smoke; Has highest calorific value. Non-caking.	89 to 92	5.5 to 4.7	4.4 to 2.1	0.9 to 0.4	3 to 7	16 to 23	3 to 10	About 1.4	74 to 82 (Not used alone for coking)	Powder, or slightly sintered.
Anthracite	Difficult to ignite; burns with very short flame.	93 to 95	3.3 to 2.1	2.6 to 1.3	1.1 to 0.4	10 to 60	2 to 6	9 to 18	1.3 to 1.8	85 to 95 (Not used for coking)	

NOTE 1.—In coal for gas making, sulphur should not exceed $1\frac{1}{4}$ per cent.

NOTE 2.—In coal for coking, sulphur should be less than $1\frac{1}{2}$ per cent, phosphorus less than 0.02 per cent.

After drying, lignites are very suitable for burning in industrial furnaces.

On the basis of heat units developed per unit of cost coal is without any doubt the cheapest fuel; but there are many other considerations which make the use of solid coal undesirable for certain industrial heating operations. These considerations are dealt with in Chapters VI and VII.

The cost of coal fluctuates with economic and political conditions, including the activities of the miners' unions. While in 1900 bituminous coal could be bought at some Monongahela River mines for 65 cents per ton, the cost in 1925 ranged from $2 to $2.30 per ton at the mine. The gradual depreciation in the purchasing value of money also influences the cost and keeps it from remaining constant. For any given locality away from the mine the cost of transportation must be added. The cost of anthracite varies greatly with the size of the lumps, anthracite being supplied in graded sizes only. An idea of the variation may be obtained from the following tabulation.

TABLE V

Average Prices of Anthracite per Gross Ton, 2240 Pounds, F. O. B. Mine, January, 1925

Broken	$8.60	Pea size	$5.40
Egg size	9.00	Buckwheat No. 1	3.10
Chestnut size	9.60	Barley	1.55

Average Prices of Bituminous Coal per Net Ton, 2000 Pounds, F. O. B. Mine, Pittsburgh District, January, 1925

Pittsburgh gas coal, run of mine	$2.15
Pittsburgh gas coal, slack	1.50
Pittsburgh steam coal, run of mine	1.95
Pittsburgh No. 8, run of mine	1 85

The solid coal weighs 75 to 110 pounds per cubic foot, its specific gravity being 1.2 to 1.8. Coal as shipped weighs 53 true pounds per cubic foot (average). A bushel of coal contains 70 to 76 pounds.

" Run of mine " is bituminous coal as broken in the mine, not having been screened. It contains both large lumps and fine coal. " Lump coal " is that which will not pass through a bar screen with openings $1\frac{1}{4}$ inches square. " Nut coal " passes

through a screen with $1\frac{1}{4}$-inch openings, but not through one with $\frac{3}{4}$-inch openings. "Slack coal" passes through the $\frac{3}{4}$-inch openings of the screen.

Powdered Coal.—As the name implies, powdered coal (sometimes called "comminuted fuel") is coal which has been reduced to a fine powder. It has the same physical and chemical characteristics as the coal from which it was made. Nevertheless, powdered coal, or coal dust, has some characteristic properties of its own, which must be mentioned because they affect the usefulness of powdered coal as a fuel for industrial furnaces.

Fineness.—This term is a general and rather indefinite measure of the size of the coal particles. Powdered coal is an aggregation of particles of various sizes. In improperly pulverized coal, grains of almost $\frac{1}{16}$-inch diameter are found alongside of fine dust particles which are no larger than $\frac{1}{1000}$ inch. In properly pulverized coal there are no grains larger than $\frac{1}{100}$ inch in diameter. A scientific indication of the fineness would be furnished by a diagram such as that given in Fig. 14, in which the abscissae represent grain diameter, while the ordinates represent per cent of weight of powder furnished by the various grain sizes.

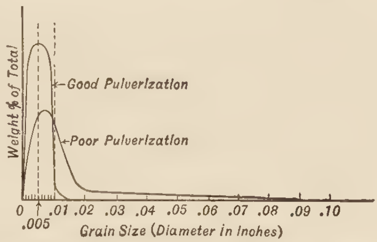


FIG. 14.—Distribution of grain sizes in powdered coal.

The measurements necessary for establishing such a diagram are so numerous and cumbersome that less scientific methods of indicating fineness have been adopted. Practice has settled on the makeshift method of judging fineness by the fraction which passes through certain standard sieves, for instance those containing 100 and 200 meshes to the inch. To understand the fineness which corresponds to these sizes, we must know the diameter of the wire, because this determines (in combination with the number of meshes) the size of the opening. The tabulation on p. 30 contains the necessary data.

It will be explained in another chapter that the size of the coarsest particles determines the volume of the combustion space. For that reason the amount which passes through a sieve with 300 meshes to the inch is of little consequence, but the amount

TABLE VI

Meshes to the linear inch	U. S. standard		British standard	
	Diameter of wire	Size of opening	Diameter of wire	Size of opening
60	0.0064 in.	0.0098 in.	0.0083 in.	0.0083 in.
100	0.0042	0.0058	0.0050	0.0050
200	0.0021	0.0029	0.0025	0.0025
323	0.0014	0.0017		

retained on a sieve with 100 meshes to the inch is of vital importance. That fraction should be practically zero, particularly for combustion in small industrial furnaces.

Moisture, Shape of Particles, Ash.—A second characteristic which affects the usefulness of powdered coal is the amount of moisture it contains. Coal can be powdered with moisture up to 7 per cent, but the energy consumption is much greater in the powdering of wet coal than it is for dry coal. Moisture has a great influence in the feeding and combustion of powdered coal. On account of the close relations between these factors, detailed discussion of the effects of moisture is postponed to the next chapter.

A third characteristic of powdered coal consists in the shape of the grains or particles. Their shape (which can only be observed under a microscope) varies with the origin of the coal and with the type of grinding equipment. In most cases the particles are oblong, needle-shaped bodies. Their surface roughness also varies with the origin and age of the coal, and with the method of grinding. A long, needle-shaped particle with a rough surface will doubtless ignite more readily than a spherical particle with a smooth surface.

A further characteristic of powdered coal is furnished by the chemical composition of the ash. With lump coal which is to be burned on the grate or to be gasified in a producer, the melting point of the ash is of great importance, due to the formation of clinkers. With powdered coal, melting temperature of the ash is likewise of importance, but the composition of the ash is at least of equal importance because the white-hot ash comes in

contact with the brickwork of the furnace and forms a slag. These factors are discussed in greater detail in the next chapter.

Cost of Preparation.—The cost of powdered coal is a very changeable quantity, in which many elements appear as contributing factors. Several years ago the author constructed the formula:

$$K_1 = 1.05K_2 + \frac{2200K_3\sqrt{U}}{W} + K_4\left(\frac{4}{\sqrt{U}} + 0.14\right), \quad . \quad . \quad (2)$$

in which K_1 = cost of a short ton of powdered coal at the furnace in dollars;

K_2 = cost of raw coal, in dollars per short ton, on the siding;

K_3 = cost of common labor, in dollars per hour, at the time of building and of installing the plant;

K_4 = cost of common labor, in dollars per hour, at the time of grinding the coal;

W = weight of coal actually pulverized per year, in short tons;

U = rated capacity of pulverizing plant in short tons per day of 24 hours.

In the equation the coefficient 1.05 takes care of the fuel used for drying, and for generating power used in crushing, powdering, and conveying. The factor 2200 in the second term represents interest, depreciation (but not maintenance), insurance, and taxes, based upon a yearly charge of $12\frac{1}{2}$ per cent of the total cost of drying, pulverizing, and conveying equipment, bins, buildings, and foundations. If any other rate M is used for the sum of the interest, depreciation, etc., multiply the factor 2200 by the ratio $M/12\frac{1}{2}$. The term U in the second and third terms indicates that the cost of the plant does not go up as fast as the capacity, and that the labor cost of pulverization goes down as the size of the plant increases. The factor 0.14 represents the cost of repairs and of maintenance.

The equation is substantially correct for average conditions. It needs modification if the cost of installation is unusual, due for instance to excessive cost of real estate or to difficulties encountered in laying foundations.

From the equation for the cost of powdered coal and from the curves in Fig. 15 it follows that the cost of preparation is quite high if the plant is small.

Coke.—In the United States coke is seldom used directly in industrial furnaces. Indirectly, large quantities are used in the making of blast-furnace gas and of blue water gas. In Europe coke is quite commonly used in industrial furnaces.

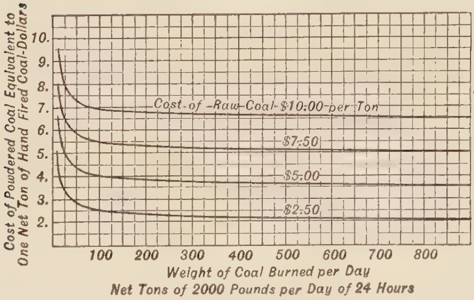


Fig. 15.—Cost of powdered coal for performing the same work as 1 ton (2000 pounds) of hand-fired coal; assuming $33\frac{1}{3}$ per cent saving in fuel by the use of powdered coal and as an offset against the value of the fuel saving the cost of preparation and burning powdered coal has been added.

A bushel of coke weighs about 40 pounds. A cubic foot contains 22 to 27 pounds. The true specific gravity of the coke material is 1.5 to 1.8; the apparent specific gravity of a solid piece of coke is .8 to 1.0.

The moisture content of coke (quenched) varies from $\frac{1}{4}$ per cent to 11 per cent, average 8 per cent. The ash content is 10 to 14 per cent. Cost (at Pittsburgh, 1923) was $5.50 per ton, with coking coal at $2.50 per ton. Small-sized coke (coke-braize) can in some localities be obtained very cheaply.

ELECTRICAL ENERGY

While electrical energy is not a fuel, it is mentioned here because it takes the place of a fuel in furnace work. Electricity is a means of transmitting energy and may be compared to a moving belt, rope, or turning shaft. It can be converted into heat very readily and such conversion is easily controlled. As a rule, electricity is sold by the kilowatt-hour, which equals 3413 B.t.u. The sales price of a kilowatt-hour depends upon many circumstances, such as the price of fuel at the generating station, construction cost of a hydro-electric plant, size and efficiency of the prime movers at the generating station, and the ratio of maxiumum demand to average demand. It is often advisable to

sacrifice speed of heating the furnace (which would place a heavy demand on the transformer, transmission line, and generating station) to a lower energy rate. For furnace work, the rate per kilowatt-hour ranged in 1923 from one to six cents at various industrial centers of the United States.

Increase in size of generating stations and improvements in design of prime movers have kept the cost of electrical energy constant for a number of years, in spite of the rising price of fuel.

Where electrical energy is available, its use is extremely convenient for many heating operations. For very intermittent demand, the cost is very high, because most central stations make a service charge or demand charge which goes on whether the furnace is in operation or not.

A charge of 2 cents per kilowatt-hour is equivalent to $5.85 for 1,000,000 B.t.u.

CHAPTER II

COMBUSTION DEVICES AND HEATING ELEMENTS

GENERAL NOTES ON COMBUSTION DEVICES

In well-designed furnaces the combustion device (or heat-liberating device) and the furnace are properly adapted to each other and form an integral combination which both generates and utilizes heat. At times it is difficult to draw the line at which heat generation stops; the latter is begun in the combustion device and is finished in the furnace. For that reason it may seem illogical to study "combustion devices," or "burners," separately. On the other hand, a much clearer view of the situation is obtained by such separate study. In the present chapter, combustion devices and heating elements are discussed, with the mental reservation that the study of these devices covers only part of the problem.

It should be noted that auxiliary devices, such as gas producers, reversing valves, pumps, oil heaters, coal pulverizers, piping systems, transformers, etc., are not described in this chapter.

No matter what fuel or other source of energy may be used in a furnace, it should be burned (or otherwise applied) in such a manner that the following requirements are met, at least approximately:

(1) It should be possible to maintain a given temperature, and that temperature should be controllable.

(2) The temperature distribution in the heating chamber should be such as to give a properly and uniformly heated product.

(3) The nature of the atmosphere in the furnace (oxidizing, neutral, reducing) should be controllable.

(4) The furnace atmosphere should not vary to any great extent at different parts of the hearth.

While these requirements sound simple, they are, in their entirety, quite difficult of fulfillment, as the following reasoning will prove:

If the combustion of fuel is the source of heat energy, the temperature of a particle of the products of combustion at any given spot in the combustion or heating chamber is the resultant of heat addition by combustion and heat abstraction by radiation and convection to or from the particle under consideration, all measured from the time it entered the combustion chamber. In the history of an elementary quantity of fuel and air, two extreme cases may be considered. In one (case *A*), fuel and air are very thoroughly mixed, and combustion is practically instantaneous. The products of combustion reach their highest temperature almost instantly (the heat is " sharp " or " rash "), and impart the highest temperature to the furnace near the place where the heat enters, causing those parts of the furnace which lie near the discharge flues to be comparatively cool. In the other extreme (case *B*), fuel and air flow side by side and mix gradually, with the result that the combustion is slow and extends throughout the length of the furnace, reaching occasionally beyond the furnace into the flues or the stack. In this case, we speak of a " lazy " flame. In case *A* the temperature distribution is uneven (unless modified by recirculation, see Volume I, page 303), but the furnace atmosphere is constant; while in case *B* the temperature is quite uniform, with variable furnace atmosphere. It is quite evident that in case *B* there must be uncombined oxygen in the early part of the gas travel. Between these two extremes many combinations exist, some of which come quite close to the ideal conditions indicated in Numbers (1) and (4) of the requirements given above. It is the purpose of this present chapter to consider devices for combustion and for the liberation of heat, with these four points in view.

Before the devices for the different fuels are investigated the following general statements should be made: Temperature, whether caused by the combustion of fuel or by electricity, is raised by increasing the supply of heat; it is lowered by reducing the supply of heat. For a given temperature, the furnace atmosphere is made reducing by introducing more fuel and less air. It is made more oxidizing by introducing less fuel and more air.

COMBUSTION DEVICES FOR GASEOUS FUELS

Classification of Burners.—Gaseous fuels are by far the easiest to control and regulate. The opening of a valve turns on more fuel; the partial closing of the same valve reduces the supply of the fuel. Gas and air can be mixed quickly or slowly, in conformity with the requirements of each individual case.

This apparent ease of control is probably the reason why so few commercial gas-burning devices are on the market compared with the endless variety of burners for oil and powdered coal. Yet there is room for improvement in gas-burning devices, because our knowledge of the physics of combustion is far from being complete.

The following classifications can be made:

I. (*A*) Gas and air are mixed in the furnace, i.e., during combustion.
   (*B*) Gas and air are mixed outside the furnace, i.e., before combustion begins.
   (*C*) Gas is mixed with some air outside the combustion chamber; the rest of the air is added in the furnace.

II. (*A*) Gas and air have pressure in excess of that of the atmosphere.
      (1) The pressure is produced mechanically.
      (2) The pressure is produced by stack effect (buoyancy).
         (*a*) Gas and air valves are separately adjustable.
         (*b*) Gas and air valves are inter-connected.
   (*B*) Either gas or air is under pressure and, by its velocity of discharge, entrains the other fluid or a mixture of air and gas, reconverting velocity into furnace pressure.

III. (*A*) Combustion takes place in one large burner.
   (*B*) Combustion starts from many small burners.

It is inadvisable to describe the combustion devices for gaseous fuels under all these classifications, because too much repetition would be caused by such a procedure. Instead, classification I will be used, and attention will be called to the other classifications as the devices are described.

(*A*) *Devices which Mix Gas and Air in the Furnace.*—With cold air and cold gas, inside mixing is, in general, not used to-day. There are, however, some exceptions to this statement. In warming up a furnace, a gas pipe is frequently put through an opening, and the gas is ignited, being allowed to find oxygen as best it can. In makeshift applications of natural gas or of coke-oven gas, inside mixing has been resorted to, sometimes with the the avowed purpose of obtaining a lazy flame. Examples of such applications are shown in Figs. 16 to 18. Figure 16 illustrates the combustion end of a gravity-discharge continuous furnace using

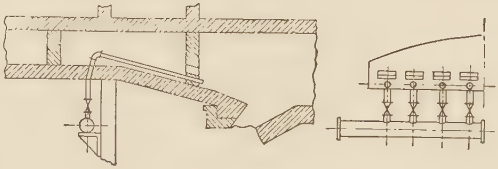


FIG. 16.—Combustion chamber of continuous furnace using coke-oven gas.

Note that mixing occurs inside furnace; gas below air; gas pipe inclined downward.

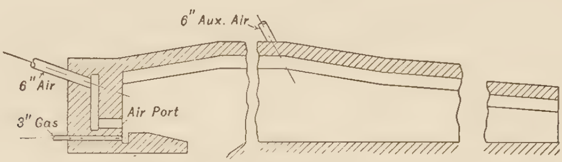


FIG. 17.—Mixing of air and coke-oven gas in two steps.

coke-oven gas. Both gas and air are given a downward direction on account of the lightness of the coke-oven gas. Figure 17 illustrates a similar arrangement for a slab-heating furnace with progressive air admission. Gas and air impinge upon each other for quick mixing. A deficiency of air is maintained at the primary combustion point, and secondary air is admitted farther back, through the roof. This arrangement increases luminosity and reduces scaling. It is discussed in greater detail in Chapter IV.

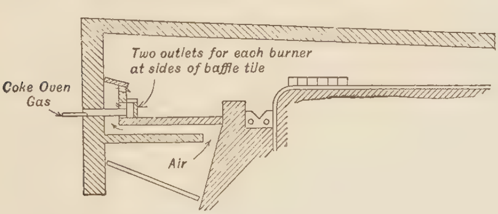
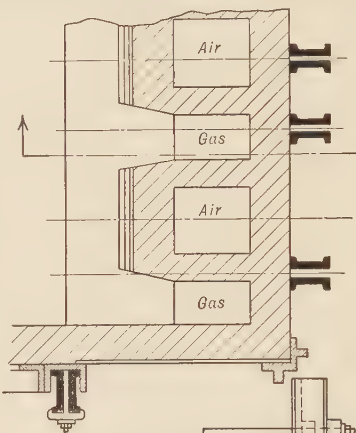


FIG. 18.—Continuous furnace with side discharge, originally coal-fired, changed over for coke-oven gas.

In the installation depicted in Fig. 17 the secondary air admission, although based on correct principles, was later removed. In both furnaces, inside mixing was probably a survival from the days when air was preheated by brick recuperators, the use of which was later discontinued. Figure 18 illustrates how a coal-fired continuous furnace with side discharge was changed over for burning coke-oven gas. Two layers of tile were placed over the old combustion space, with the intention of getting whatever air-preheating effect that arrangement would allow. The gas is brought into the furnace through small pipes and is allowed to mix with the air in stages. Some air can enter directly from the outside (by induction) through the 4-inch pipe which surrounds the gas pipe. Partly preheated air can mix with the gas as it leaves the 4-inch pipe, which lies in an 8-inch pipe, and finally air swoops down through narrow slits over the gas and air mixture. Although all of the mixing occurs in the furnace, some premixing takes place before combustion begins; for



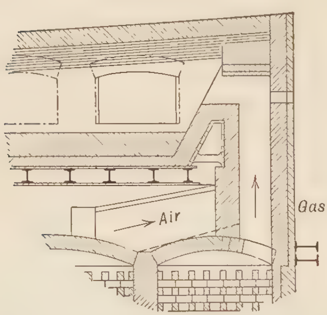


FIG. 19.—Ports for air and raw producer gas in regenerative heating furnace.

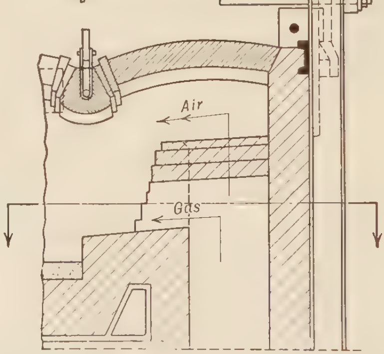


FIG. 20.—Ports in regenerative heating furnace.
Note that gas is admitted below air.

that reason, the device does not wholly belong in the class here considered.

Inside mixing is necessary if the air is highly preheated or if the gas is hot and dirty. In that case, we seldom speak of burners, but refer to "ports." In the design of ports, a difference is made between those of regenerative furnaces and those of recuperative furnaces. In the former type, the combustion and discharge ends exchange places with every reversal. Oxide, dust, and slag are apt to clog up the ports, if they are small. In recuperative furnaces that limitation does not exist, and the ports may be made small. This statement holds particularly for the air ports.

Ports of regenerative heating furnaces are shown in Figs. 19, 20, and 21. It will be observed that ports are openings in the wall through which gas and air pass out side by side. The question of flame length resulting from various port designs concerns every furnace designer. If gas and air pass out in parallel streams and with approximately equal velocity, combustion takes place by diffusion of gas and air through each other, aided by the increase of volume due to combustion. The diffusion angle may be taken to be three degrees on each side. Combustion will be complete when the edge of one jet has diffused beyond the center line of the adjacent jet.

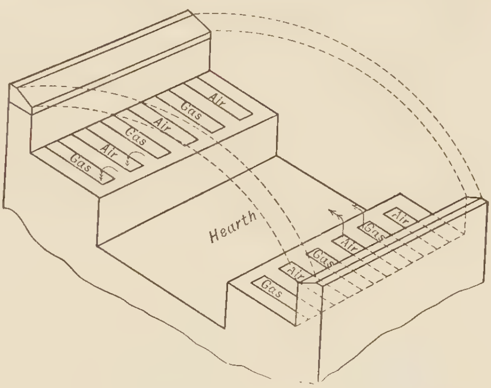


FIG. 21.—Perspective view of part of skelp-heating furnace.

Note arrangement of gas and air ports.

The diffusion angle of three to four degrees does not hold if one of the fluids (gas or air) has a much higher velocity than the other. In that case, diffusion gives way to induction or entrainment (see Volume I, page 295) and the act of mixing is quickened.

The permissible velocity of air and gas in passing through the ports of regenerative furnaces is discussed in Volume I, Chapter VI.

If the stock being heated is of such a nature that it would suffer damage by oxidation, the gas ports are located under the

air ports for the purpose of bathing the charge in gas rather than in air.

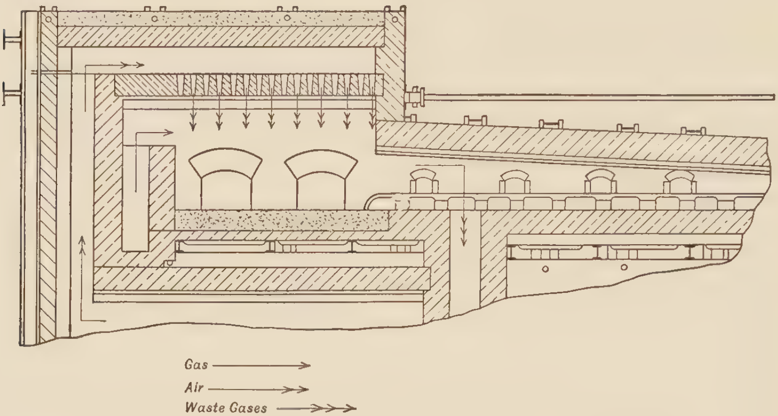


FIG. 22.—Continuous furnace with overfired soaking hearth.
Note many small ports for preheated air. Air jets penetrate and mix with gas blanket below them.

If the stock is to be heated mainly by radiation, the ports face the roof as in Fig. 21, directing the flame along the roof.

If highly preheated air coming from a recuperator flows through the ports, the latter can be made smaller and more numerous than they are in reversing furnaces. The same is true of ports in that type of regenerative furnace in which the direction of flow is constant. Examples of furnaces with many small ports for preheated air are shown in Figs. 22, 23, and 24. In Fig. 22 the ports are distributed over a large portion of the roof. This

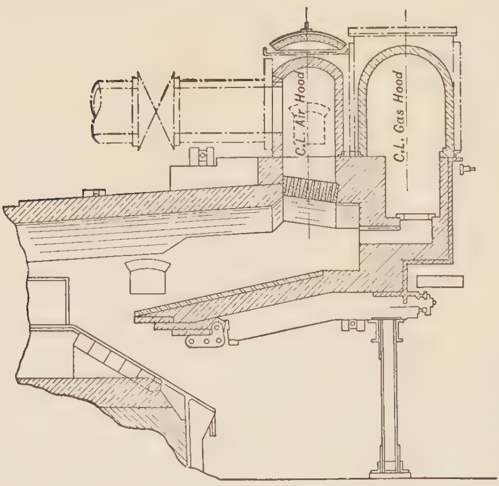


FIG. 23.—Discharge end of continuous furnace.
Note that gas enters below air, which enters in many small jets, at right angles to gas flow.

arrangement results in the maintaining of a practically uniform temperature over the whole hearth and produces a reducing or neutral atmosphere at all places on the hearth. While this very good arrangement has not yet been introduced in the United States, the designs of Figs. 23 and 24 are used here. Both represent ports at the inlet end of continuous furnaces. The purpose of this design is, doubtless, the quick mixing of air and gas, without stratification. The velocity of the air through the ports should be such that it is practically all spent by the time the vertical air jet reaches the bottom of the horizontal gas jet. The finer the air holes, the higher the air velocity must be to penetrate a given distance downward. The theory of jets is explained in Volume I, page 297.

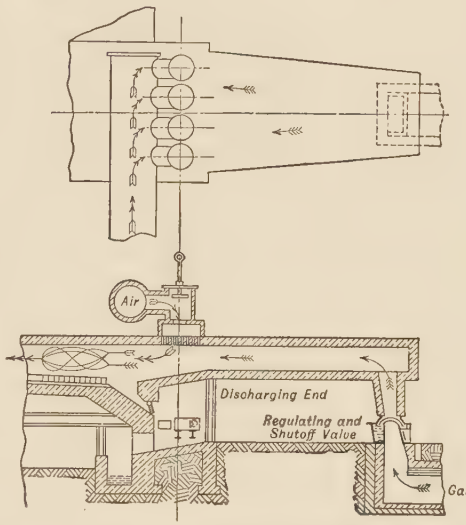


Fig. 24.—Continuous regenerative billet-heating furnace.

Note that air enters gas stream at right angles in many small streams.

Devices with Partial Premixing.—If a quicker combustion is desired than can be obtained with total inside mixing, partial or total premixing of gas and air is resorted to. Since the devices by which mixing is effected partly outside of the furnace and partly inside stand between (*A*) (all inside) and (*B*) (all outside), they will be considered next. To that group belong the various injector burners, in which the gas by its momentum induces air and starts mixing outside of the furnace, without, however, completing the mixing action until gas and air are inside of the furnace. A good example of this method of mixing is furnished by the well-known "Weardale Burner," which is very commonly used in England and upon the European Continent, but which, for some reason or other, has not been used to any extent in the

United States.[1] This type of burner is illustrated in Fig. 25. The gas flows from the gas duct through a nozzle, the mouth of which lies in an air nozzle. Mixing begins in the air nozzle, but is not completed there. With such a burner in the crown of the arch, the flame spreads over a definite area of the hearth; a number of burners can be arranged in such a manner that the flame covers the whole hearth area. If producer gas is used and the air preheated to about 1300° F. there is no difficulty in obtaining a furnace temperature of 2300° F. with natural draft, but for temperatures of 2400° F. and upwards a considerable economy of fuel can be obtained by using air under a slight pressure. It has been shown by independent investigators that this economy is quite definite; the explanation, apparently, is that the increased velocity of air provides quicker mixing and more complete combustion.

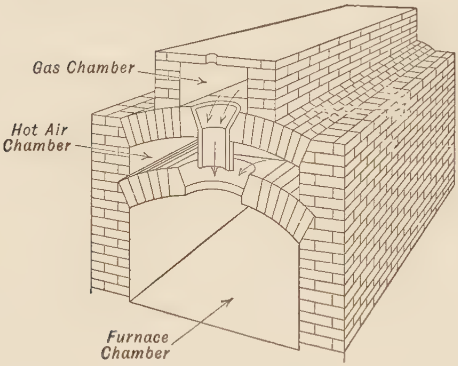


Fig. 25.—Furnace of the Weardale type, with injector burner, using hot gas and preheated air.

A device which is much used in furnaces where many burners

[1] The probable reason for the non-use of the Weardale Burner in the United States is the difficulty of keeping the roof tight with widely varying rates of firing. Against this opinion may be cited a letter from one of the foremost builders of Weardale furnaces in England. They write: "We are surprised to hear that Weardale furnaces are not in use in the United States because they are driven so hard that it is impossible to keep the roof from leaking. We have very many billet furnaces which are worked up to their full capacity, and with producer gas it would not be possible to drive them any harder under these conditions. We do not find any difficulty whatever in keeping the roofs tight and no special precautions are taken. These roofs in the combustion chambers are built of the very best firebrick which we have in the country, called 'Glenboig Fireclay.' The roof in the way of the combustion chamber may be rebuilt in, say, about two years, but the remainder of the roof in, say, a continuous billet furnace where the temperature falls off toward the charging end, will last for many years. The answer, therefore, to your question is that no precautions are taken beyond supplying the best firebrick and building the roof in a careful manner."

are required consists simply of a tee with a short section of outlet pipe, as shown in Fig. 26, both gas and air being supplied under pressure. This arrangement is further discussed in Chapter IV.

In a much larger number of furnaces jets of gaseous fuel induce air directly from the atmosphere, with all possible degrees

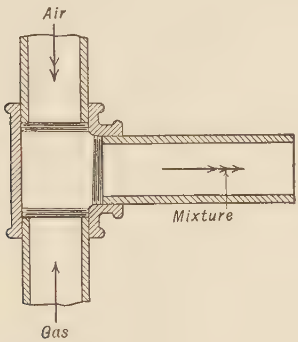


FIG. 26.—Simple form of mixer for gas and air.

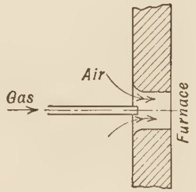


FIG. 27.—Diagram of gas burner producing imperfect mixing.

of premixing. The character of the flame in this case depends to a very large extent upon the method and the thoroughness of the mixing. Figures 27, 28, and 29 show, rather diagrammatically, three arrangements of inducing air by gas. The arrangement of

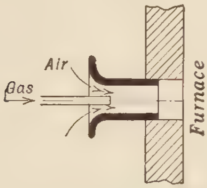


FIG. 28.—Diagram of gas burner producing fairly good mixing.

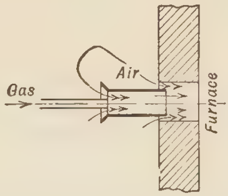


FIG. 29.—Diagram of gas burner with two-stage induction, producing good mixing.

Fig. 27 results in very imperfect mixing. That of Fig. 28 provides better mixing because the path is longer, but there is greater danger of blowing back of the flame. Figure 29 delivers a nonexplosive mixture of gas and air from the mouth of the intermediate tube and produces reasonably quick combustion with a definite place for the combustion. In large burners quick mixing

is occasionally produced by admitting gas in a ring-shaped stream which induces air by its inner and outer surfaces, as indicated in Fig. 30. In other large burners use is made of the fact that in a Venturi tube the pressure at the throat drops considerably, so that air can be sucked into the gas stream and a certain amount of premixing can be had, as indicated in Fig. 31. The principles shown in Figs. 30 and 31 may be combined. Quite a number of these burners have been designed for burning blast-furnace gas in blast-furnace stoves or under boilers. It may be repeated that many small burners result in short flames and that one large burner produces a long flame.

None of these arrangements furnishes, in itself, any guarantee

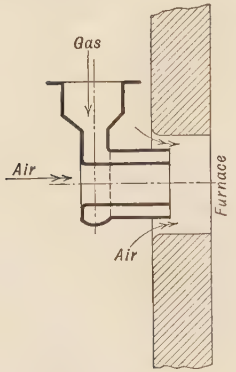


FIG. 30.—Ring burner for quick mixing of large quantities of gas and air.

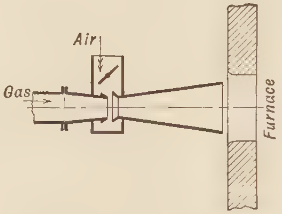


FIG. 31.—Venturi-tube mixing device.

of correct combustion and good heating. To that end, it is necessary to maintain a constant gas-to-air ratio, which is quite difficult. With rich gases, such as natural gas, the jet cannot be given enough momentum to entrain sufficient combustion air unless a pressure of about 10 pounds per square inch is carried in the gas line and the mixing equipment is designed with minimum frictional resistance. Stack draft must then be depended upon to bring enough combustion air into the furnace. In consequence, opening and closing of the damper and of the door of the furnace changes the gas-to-air ratio considerably. A design in which such conditions exist should be avoided.

Better results are obtained with similar designs, if both gas and air are delivered with some pressure, as indicated in Fig. 32.

The intensity or degree of premixing can be adjusted by the length (1)–(2) in relation to the diameter of the pipe. If (1)–(2) is long, a very thorough premixing is obtained. The mixing which takes place in a cone of about 20 degrees is complete, if the 20-degree cone lies entirely within the tube. It is hardly necessary to remark that this value holds good if the velocity of the flow lies above the critical velocity, below which turbulence ceases and stream-line flow exists, because in practice velocities of flow are always above the critical velocity to avoid blowing back of the flame. While the arrangement of Fig. 32 is doubtless very good for positive control of furnace atmosphere if both gas and air are delivered under pressure, it is frequently disliked by furnace

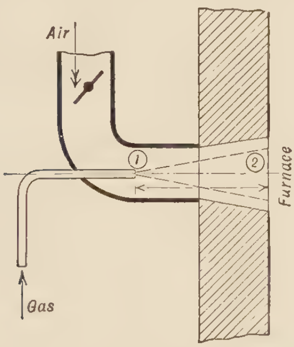


Fig. 32.—Mixer with gas and all of combustion air under pressure.

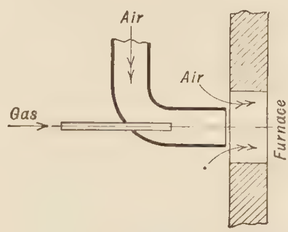


Fig. 33.—Mixer with gas and part of air under pressure, inducing remainder of air.

attendants, because they cannot observe the combustion. The arrangement of Fig. 33 avoids this drawback, but it is less positive with regard to maintaining a fixed gas-to-air ratio. If a shutter or register is used over the free air inlet, the furnace atmosphere can be adjusted, but it is not easy to observe the combustion. An observation hole, covered with pyrex glass, can, of course, be provided.

The design of Fig. 33 has some advantages for rich fuels such as natural gas, because a definite non-explosive mixture of gas and air can be sent out of the tube, allowing the rest to be induced at the opening. In this manner, furnace pressure can be maintained, and yet there will be no back-firing into the mixing tube or panting of the flame.

A practical application of a gas-burning device, in which both gas and air are delivered under some pressure and the mixture induces additional air, is shown in Fig. 34. In this case it is intended to produce an oxidizing atmosphere for burning clay products.

Figure 35 shows a device in which the attempt is made to

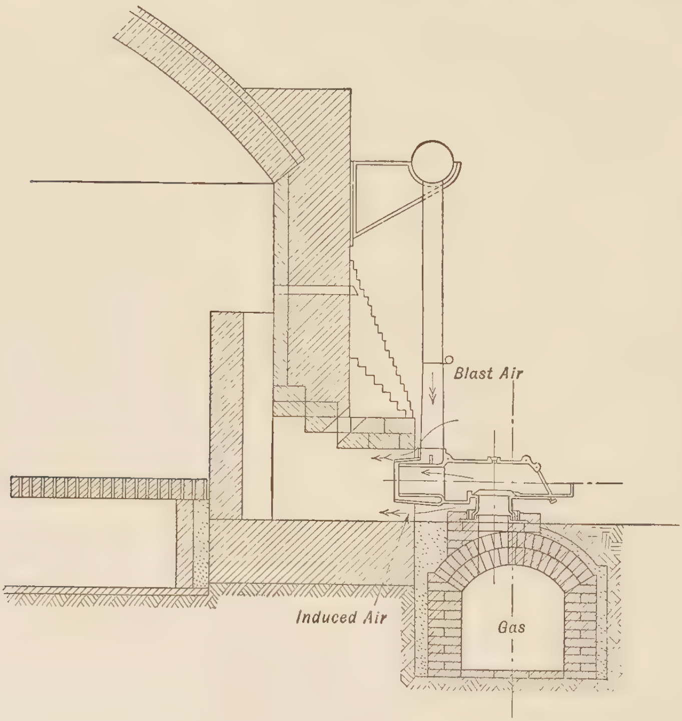


Fig. 34.—Mixer for producer gas applied to brick kiln. Gas and part of air under pressure induce remainder of air.

retain the excellent mixing properties of the Venturi tube while providing for the adjustment of both quantity and proportion of air and gas, both of the latter being supplied under pressure.

For all these arrangements the following facts should be borne in mind. The better and more thorough the premixing, the more fuel can be burned in unit time in a given combustion space. The hotter the air blast, the greater the danger of back-firing, even with a deficiency of air. Data on flame propagation veloc-

ities are somewhat scarce, particularly for high temperatures; the following data are the best available at the present time: For slow combustion (gases not in motion), the velocity of propagation in mixtures of air with producer gas or natural gas equals 7 feet per second; with illuminating gas, 13 feet per second; with hydrogen, 30 feet per second. When the gas mixture is in motion the velocity is at least twice the above, and frequently still higher, depending upon the amount of turbulence. These figures apply to cold gas and cold air at atmospheric pressure, and with approximately the correct or ideal proportions of gas and air. If the mixture is much richer or leaner than the ideal the flame propagation velocity is greatly reduced. Increase in temperature causes an increase in propagation velocity somewhat in excess of the ratio of absolute temperatures (although the average velocity of the molecules varies as the square root of the absolute temperatures).

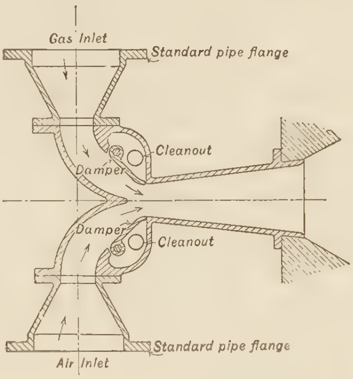


FIG. 35.—Mixer with Venturi throat, adjustable air and gas openings.

Fortunately, in view of the many variables, it is not necessary to know the propagation velocity with great accuracy, because furnace engineers have learned how to help themselves. The velocity of the gas mixture issuing from the burners is made sufficiently high to prevent back-lighting, and is then slowed down beyond the burner by spreading the gas stream along the roof, or by using a flaring ignition passage.

Devices with Total Premixing.—As previously stated, smallest furnace volume or, in other words, greatest heating capacity per cubic foot of furnace volume is obtained by thorough premixing of gas and combustion air in the burner outside of the furnace. Figure 32, which was referred to above, furnishes an example of such construction, provided the distance (1)–(2) is made long enough. A practical application of this design for a continuous heating furnace is shown in Fig. 36. It will be noted that the fuel and air mixture travels over a long path before it enters the furnace chamber proper.

All devices that involve complete mixing of fuel gas and air, before the mixture enters the furnace chamber proper, have certain features in common, which will now be discussed. In order to prevent back-firing the combustible mixture must enter the furnace chamber with a velocity which is in excess of the velocity of flame propagation. The greater the velocity of the combustible mixture, the greater is the distance from the point at which the mixture enters the combustion chamber to the point at which combustion begins. As a matter of fact, combustion always

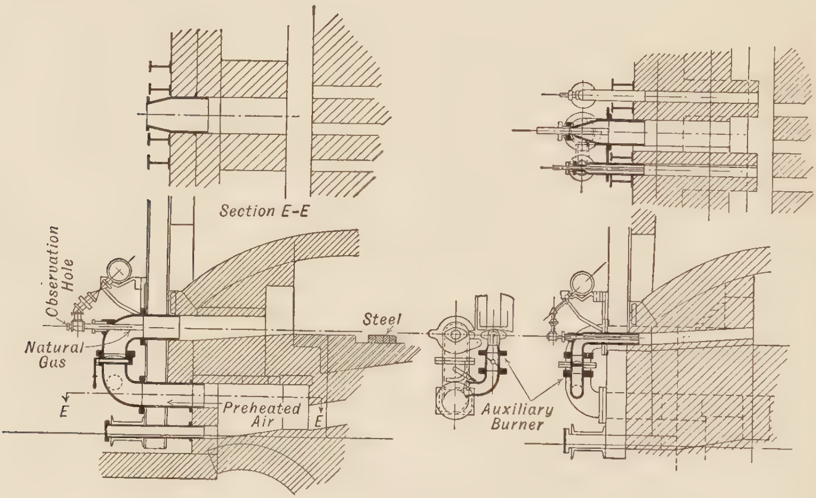


Fig. 36.—Mixer for natural gas and preheated air, as applied to a continuous furnace.

Note that both air and gas are under pressure; burner openings closed to atmosphere, no induction. Auxiliary burners provide for operation at low rates of heating.

begins at the place where the velocity of flow equals the velocity of flame propagation. If the velocity at entrance exactly equals the velocity of flame propagation a limiting case is reached, and the flame may extend back into the mixing tube. Because of back-firing, or "back-lighting," the furnace cannot be operated at a lower rate of fuel supply than the one which corresponds to the limiting case. These conditions result in troublesome furnace operation unless the rate of heating is kept fairly constant or special designs are used. A wide range of heating capacity of the furnace can, for instance, be obtained by admitting the gas and

air mixture through a small opening, which means that the mixture enters at a considerable velocity whenever the furnace is driven hard. A high velocity of the entering gaseous mixture carries the flame very far away from the burner unless the burning mixture impinges upon loose material as indicated in Fig. 37. A similar result is obtained if the flame spreads in a thin sheet over a hot wall, for instance, by being spread like a fan tail under the arch of the furnace, as shown in Fig. 38. In the design shown in Fig. 36, a wide range of heating is obtained by a large number of burners, some of which can be turned off if the furnace is to be kept warm while the mill is shut down. A convergent-divergent burner nozzle similar to the one shown in Fig. 37 is illustrated in

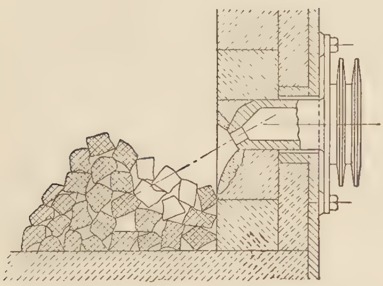


Fig. 37.—Gas burner throwing jet of burning mixture into loose refractory material.

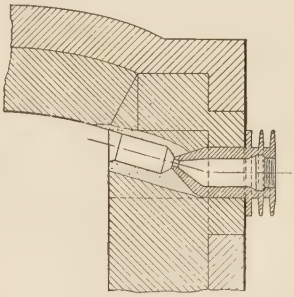


Fig. 38.—Convergent-divergent burner nozzle spreading sheet of gases under arch.

Fig. 39. This type of nozzle has a narrow range of adjustment of flame capacity, if an explosive mixture of air and gas is delivered by it. For that reason it is frequently changed in practice by allowing an open space between the nozzle and the furnace in a manner similar to that shown in Fig. 33. The arrangement is then no better than Fig. 33. The nozzle that was illustrated in Fig. 39 has recently been improved, as shown by Fig. 40. A few small lighting holes allow a portion of the premixed gas and air to flow into the annular space which surrounds the main discharge orifice of the nozzle. In this annular space a flame burns without being disturbed by the blast of gas and air passing through the main orifice; it serves as a pilot flame which keeps the major portion of the fuel ignited at all times. Combustion begins directly at the nozzle. The improved nozzle is usually set $\frac{1}{4}$ inch

to 1 inch away from the furnace wall, as shown in Fig. 41. This arrangement has two effects. It keeps the nozzle from becoming overheated and from transmitting the heat back to the pipe carrying the explosive mixture. But it also admits cold air.

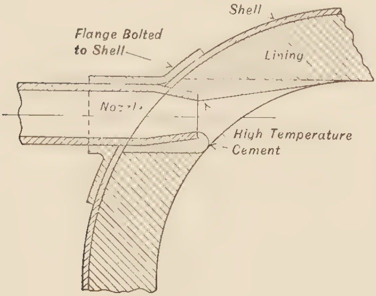


FIG. 39.—Convergent-divergent nozzle for premixed air and gas.

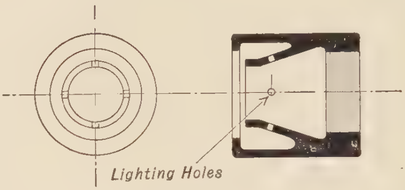


FIG. 40.—Nozzle for premixed gas and air, with lighting holes for pilot flame.

A fairly definite place can be assigned to the point of combustion if the combustion channel or tunnel is flared out gradually as it approaches the furnace chamber. Although this design is

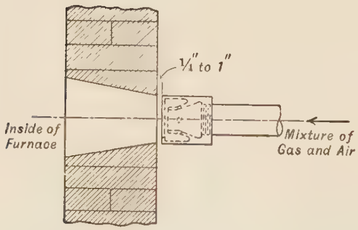


FIG. 41.—Location of nozzle with respect to furnace wall, permitting some induction of air.

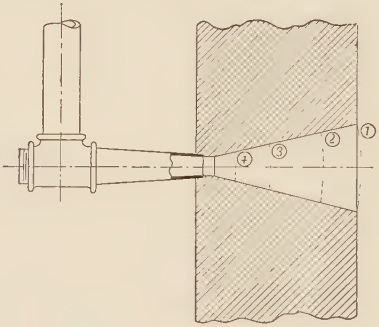


FIG. 42.—Location of plane of ignition at varying rates of flow.

very desirable, it is not as common with gas-fired furnaces as it should be. It is much more necessary with oil-fired furnaces and is, therefore, discussed in detail under the heading of "Combustion Devices for Liquid Fuel." With a gradually flaring pas-

sage or tunnel of this kind from the burner to the interior of the furnace, if the areas are correctly proportioned, combustion begins near the wide end of the cone or channel, as at (1) in Fig. 42, when the furnace is being operated at its maximum rate. At the lowest rate of firing, combustion begins nearer the narrow end, as at (3). If, however, the areas have been made somewhat larger than required, or if the rate of flame propagation is greater than was expected when the areas were proportioned, then the maximum and minimum positions are (2) and (4), respectively. The diverging or flaring passage, then, compensates throughout a fairly wide range for variations in thoroughness of the mixing of gas and air and for the corresponding variations in rate of flame propagation.

If an explosive gas and air mixture is burned in a furnace with thin walls there is danger of much heat being transmitted back to that portion of the supply pipe in which the fuel and air mixture travels at comparatively low velocity, and of producing backlighting. For the purpose of dissipating the heat before it reaches the enlarged section of the supply pipe ribs have occasionally been provided for heat radiation, as indicated in Fig. 37, above referred to. These ribs are not necessary if the furnace walls are thick, as in Fig. 36, or if the premixing of the gas and air occurs only a short distance away from the furnace, as also shown in Fig. 36.

In the classification at the beginning of the chapter the statement was made that the premixing of gas and air may be accomplished by various means. Gas and air may be brought to the burner in separate ducts, as shown in Fig. 36, or they may be mixed in a fan and brought to the furnace by the pressure produced by the fan, or else one of the component parts of the combustible mixture may be used to induce the other part of the mixture. The merits of these devices are discussed in detail under the heading of "Control of Furnace Atmosphere."

In the designs which carry an explosive mixture a great distance dangers arise, in spite of all precautions which may be provided, if highly preheated air is used. In that case any design in which air and gas are brought to the furnace in separate ducts is very much to be preferred. Figure 36, above referred to, illustrates this principle. On the other hand, the advantages of proportionate mixing, which are more fully discussed in Chapter

IV, are so great that engineers have designed arrangements in which the mixing takes place directly at the burner. Such an arrangement is illustrated in Fig. 43. A non-explosive mixture of gas and air (in a constant ratio) is delivered to a needle valve at a pressure of ½ pound to 3 pounds per square inch. The rest of the combustion air is inspirated by the jet of non-explosive mixture and is mixed in the taper tube which fits up against the furnace and discharges into the ignition cone.

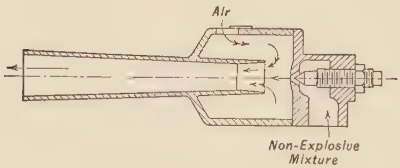


Fig. 43.—Inspirator in which a non-explosive mixture of gas and air, under pressure, induces and mixes with the remainder of the air in a Venturi throat.

A few paragraphs above the statement was made that producer gas is usually sent into furnaces through ports, because of the difficulties which arise if premixing of such a gas with air is attempted in burners. With cold or slightly preheated combustion air, these difficulties have been very successfully overcome in an excellent burner or injector for raw producer gas. This device, which may also be used for clean gas, is shown in Fig. 44. The admission of gas is controlled by a valve, which is either wide open or dead shut. Because cold tar has a tendency to freeze, two handwheels are used for controlling the valve. The upper one is used for opening and closing the valve, while the

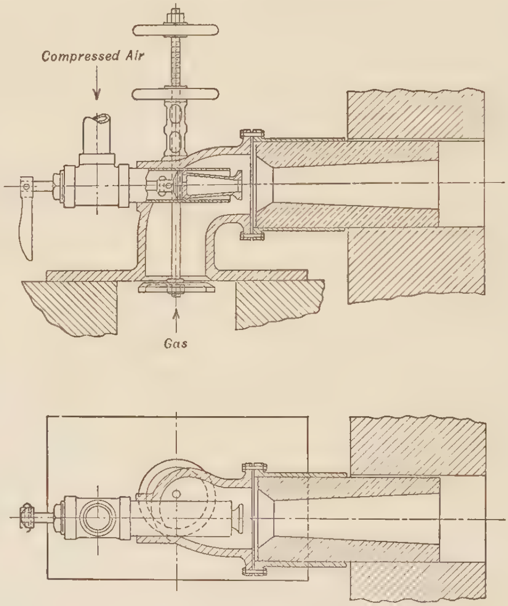


Fig. 44.—Burner for raw producer gas. Note the two handwheels for freeing gas valve when stuck with tar.

lower one is used only for cracking the valve off its seat. To this end the lower handwheel is given a turn or two and is thereby lifted off its seat. The valve stem is then given a smart blow with a hammer. By this action the brittle tar is shattered, and the valve can be opened without any trouble.

With the gas valve wide open the flow of gas is regulated by either the inducing or the baffling effect of a nozzle for blower air, which is shown in Fig. 44 in its proper relation to the rest of the burner, and which is shown separately to a large scale in Fig. 45. The inducing effect of the nozzle which, by the way, introduces all of the air used for combustion, is varied by the twisting of a slide or clover-leaf valve in the back part of the nozzle. This valve, as its position is changed, directs varying proportions of the air either through the center or around the outside of the nozzle, allowing any combination between the rates of flow through the two passages. The air which passes through the center of the nozzle produces a strong inducing or entraining effect, whereas the air passing around the outside is deflected radially at the tip and has a tendency to hold the gas back. Since the purpose of the air nozzle is to furnish air for combustion and to induce the proper amount of gas, a wide range of regulation is necessary both for quantity of gas and air and for gas-to-air ratio. This dual regulation is obtained by the above-mentioned clover-leaf valve and a throttle in the air line. The gas and air mixture passes through an ignition tube of refractory tile which is exposed to back radiation from the furnace. All tarry matter is thoroughly gasified and made ready for combustion in the ignition tube.

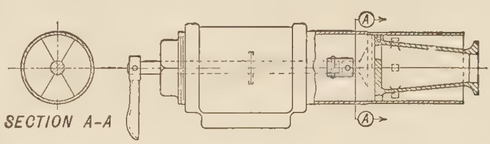


Fig. 45.—Nozzle for raw producer gas burner, with valve for regulating induction of gas.

The size of the valve for a given gas flow is varied with the available room. If much space is available, large valves are used, and the air pressure is kept down to 3 ounces per square inch. In most cases the pressure can be kept below a pound, but in a few cases as much as 5 pounds per square inch has to be used. The burner can take care of air which has been preheated up to 700° F.

Capacity of Gas Burners.—An important question in connection with gas burners is: What is the capacity of a given burner? If furnaces or burners are purchased from reputable builders, the capacity is known from data furnished by these builders; but if special furnaces are to be built, standard capacities are not available. In such a case the information given below will be helpful.

A complete gas-combustion system consists of apparatus for moving air and gas, pipe lines, apparatus for mixing air and gas, and one or more burners in or at the furnace. From the descriptions and illustrations given in this section it is evident that these four elements are grouped in all sorts of combinations. For that reason, only general data can be given here on the capacities of combustion appliances for gaseous fuels.

Attention will first be directed to the burner, that is to say, to the pipe or opening which delivers gas, or gas and air, to the place of combustion. The size of a burner is determined by the gas and air volume flowing in unit time, and by the permissible gas and air velocities. If gas and air are delivered under pressure a very wide range of velocities is permissible, but nevertheless there are limiting features. If the velocities are very low, too much heat radiates back into the burner, and back-fire occurs in the case of premixing. Besides, with too low velocities, the flame has no direction. If the velocities are too high, the flame is blown too far away from the burner, and too much power is used for compressing the gas and the air. For average driving of the furnace, a velocity of 30 to 50 feet per second at the burner outlet is advisable as a good compromise between the conflicting requirements, except for explosive mixtures. For explosive mixtures, normal velocities up to 100 feet per second or even 150 feet per second are advisable, particularly if the mixtures contain preheated air. Lower velocities of the non-explosive mixtures may have to be used, if the gas pressure is extremely low; for instance, a velocity of 50 feet per second for natural gas requires a pressure of about $\frac{3}{8}$ inch of water. In such cases the gas may be induced by air under pressure.

High velocities must be dissipated at the entrance to the furnace. To that end the flame is often directed along the roof, for the purpose of spreading out the gases and slowing them down quickly by friction. In any event, a flaring ignition tile is advantageous. At the place where the tile empties into the

combustion chamber the velocity may be as low as 10 feet per second if volume change by combustion is disregarded.

If raw producer gas is used as a fuel, the gas velocity in the ports is limited by the gas pressure and by the buoyancy of the gas, if it passes upward through regenerators. In general, it is not advisable to figure with a gas pressure of more than $\frac{3}{4}$ inch at the ports, because a greater pressure results in difficult operation of the gas producers. The velocity of the gas which corresponds to that pressure lies between 100 and 120 feet per second, depending upon the temperature at which the gas arrives at the port. See Volume I, page 260.

If the gas (clean producer gas, city gas, etc.) induces the air, the attainable velocities depend upon the composition of the gas, the pressure of the gas, and the pressure in the combustion chamber. The following reasoning will make the meaning of this statement clear. In Fig. 46, c_1 is the velocity of the entering air, c_2 the velocity of the gas leaving the gas pipe, and c_3 an intermediate velocity at the place where the gas jet has entrained all the air; the jet does not fill the duct at that place and is surrounded by eddies, as indicated in the illustration. c_4 is the final velocity of the air and gas mixture. Let the composition of the gas be such that one pound of gas requires n pounds of air. Then, from the conservation of momentum, $nc_1+c_2=(1+n)c_3$. The comparatively great velocity c_3 is converted into the lower velocity c_4, by which action some velocity is converted into pressure and some into heat. The pressure which must be overcome by the conversion of high velocity into low velocity is the pressure difference between (3) and (4), Fig. 46. At point (3) there exists a vacuum equal to $\frac{(c_1)^2}{2g \cdot v_1}$, where v_1 is the specific volume of the air entering the burner. If the entrance is sharp, instead of being well rounded, the vacuum expressed by this term must be multiplied by the square of the reciprocal of the coefficient of contraction. The maximum vacuum, therefore, can be $(1.6)^2\left(\frac{c_1^2}{2gv_1}\right)$. At point (4), there exists a furnace pressure

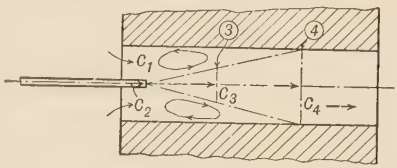


FIG. 46.—Diagram illustrating induction of air by a jet of gas.

P_4. It is not likely that any of the velocity head at (4) can be converted into pressure, because the change in velocity at the the entrance into the furnace is too sudden. The total pressure difference, then, is $\frac{c_1^2}{2gv_1}+P_4$ if there is no contraction, and $(1.6)^2\left(\frac{c_1^2}{2gv_1}\right)+P_4$ if there is maximum contraction. If the conversion of velocity head into pressure head were ideal (without losses), the pressure rise would be equal to the whole difference in velocity head or $\left[\frac{(c_3)^2}{2g}-\frac{(c_4)^2}{2g}\right]\frac{1}{v_4}$. On account of losses caused by eddy currents, only a fraction f of their difference is available. From Carnot's Theorem, the maximum possible fraction is $f_{\max}=\dfrac{2\times\frac{c_4}{c_3}}{1+\frac{c_4}{c_3}}$ if the velocity is uniformly distributed over the cross-section. Actually, f is less, because the velocity is high in the center and low at the edges. Equating the two expressions for pressure rise, we obtain

$$f\left[\frac{c_3^2}{2g}-\frac{c_4^2}{2g}\right]\times\frac{1}{v_4}=\frac{c_1^2}{2gv_1}+P_4, \qquad (3)$$

from which it follows that

$$c_3=\sqrt{\frac{v_4}{f}\left[\frac{c_1^2}{v_1}+2gP_4\right]+c_4^2}. \qquad (4)$$

The velocity of the inducing gas stream then must be:

$$c_2=(n+1)\sqrt{\frac{v_4}{f}\left[\frac{c_1^2}{v_1}+2gP_4\right]+c_4^2}-nc_1. \qquad (5)$$

Practical use of this equation is somewhat complicated by the fact that f, the conversion factor, is not constant, but is an unknown function of the ratio n, the ratio c_4/c_3, and the velocity distribution in the jet. The relation between $f_{\max}$ and c_4/c_3 appears in the following table:

TABLE VII

c_4/c_3	0.9	0.8	0.7	0.6	0.5
f_{max}	0.95	0.89	0.82	0.75	0.67

As above stated, f is less than these values. Experiments indicate that the value of f drops off as the ratio n of air to gas increases; it is less for low injection pressures than for high; and it increases as the ratio of jet diameter to induction pipe diameter decreases. In the following table are shown ratios of the values of f found by experiment, to the ideal values f_{max}:

TABLE VIII

Ratio n.	1		2		5		10		
Injection pressure lb. /sq. in.	2	5	2	5	2	5	5	10	15
Ratio $\frac{f_{actual}}{f_{max}}$.	0.79	0.82	0.85	0.90	0.65	0.86	0.50	0.60	0.64

While it is possible to substitute the algebraic expression for f_{max} and to solve for c_3, the final equation resulting from that procedure is not only much too complicated for any practical use, but it also neglects the fact that the actual values of f are less than f_{max}. It is much easier to figure with an average value of f, say, 50 per cent, and to go over the calculations once more if the resulting value of c_4/c_3 corresponds to a value of f which differs considerably from the assumed value of 50 per cent.

To appreciate the information conveyed by Equation (5), one should compute a few examples. For natural gas as fuel, some simplifications can be made. Since $n=16$, c_1 and c_4 are practically alike, and v_4 and v_1 are nearly equal, the equation is then simplified to

$$c_3 = 17\sqrt{\left(\frac{1}{f}+1\right)(c_4)^2+\frac{2gP_4V}{f}}-16c_4. \quad . \quad . \quad . \quad (6)$$

With $f=0.5$ and $P_4=\frac{1}{40}$ inch of water, the following series of corresponding values were found for an induction duct with well-rounded entrance (no contraction).

TABLE IX

c_4 ft./sec.	10	20	30	40	50	100
c_2 ft./sec.	234	320	440	570	690	1370
Gas pressure, lb./sq. in.	0.31	0.57	1.05	1.76	2.58	10.6

For clean producer gas, c_1 equals about half of c_4; $n=1.25$ and $v_1=v_4$; then on the basis of $f=0.5$ and $P_4=\frac{1}{40}$ inch of water, the following series is easily computed from

$$c_2=2.25\sqrt{1.5(c_4)^2+4gP_4v}-\frac{1.25}{2}c_4. \quad . \quad . \quad . \quad (7)$$

TABLE X

c_4 ft./sec.	10	20	40	100
c_2 ft./sec.	50.3	60.1	95	217
Gas pressure, in. of water	0.58	0.82	2.05	10.7

From these values [2] it is readily seen that it is easy to induce a sufficient amount of combustion air by producer gas, but that it requires a very high gas pressure to induce enough combustion air by natural gas, even against the very moderate furnace pressure of $\frac{1}{40}$ inch of water. For that reason, practice favors the system by which air under pressure becomes the inducing medium, and either gas or a mixture of gas and air is induced. For exceptions to this statement, see Chapter IV on Control of Furnace Atmosphere.

[2] It should be understood that the values in the tables on this and the preceding pages are approximations only, since the value of f (fraction of restitution of pressure) is not constant as assumed, but varies as indicated in the table previously given.

As an example of the case in which the gas is induced by the air, an analysis will be made of a burner such as is shown in Fig. 47. The air used for combustion is to induce 1200 cubic feet of natural gas per hour. Assume a velocity c_4 of the gas and air mixture of 40 feet per second and a furnace pressure of $\frac{1}{40}$ inch of water. Let it also be assumed that the area of the gas openings is $\frac{1}{10}$ of that of the straight induction tube.

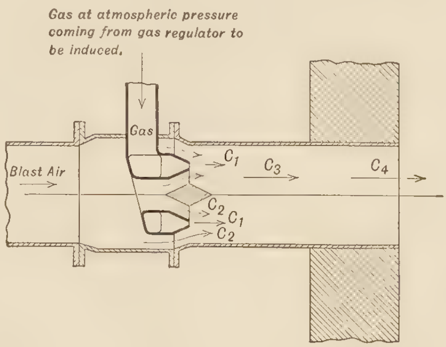


FIG. 47.—Ring burner in which air induces gas.

v_1 (of gas) = 20.3 cubic feet per pound = specific volume.

v_2 (of air) = 13.2 cubic feet per pound = specific volume.

$n = \frac{1}{16}$ pound of gas per pound of air.

$$v_4 \text{ (of mixture)} = \frac{(16\times 13.2)+20.3}{17} = 13.6 \text{ cubic feet per pound.}$$

Sixteen pounds of air per pound of gas correspond to 10.4 cubic feet of air per cubic foot of gas (specific gravity of gas referred to air = 0.65).

$$c_1 = 10 \times \frac{1}{11.4} \times 40 = 35 \text{ feet per second.}$$

$$c_2 = (n+1)\sqrt{\frac{v_4}{f}\left[\frac{c_1^2}{v_1} + 2gP_4\right] + c_4^2} - nc_1$$

$$= \left(\frac{1}{16}+1\right)\sqrt{\frac{13.6}{0.5}\left[\frac{(35)^2}{20.3} + (64.4)\left(\frac{0.025}{12}\times 62.4\right)\right] + (40)^2}$$
$$- \tfrac{1}{16}\times 35$$

$$= 60.3 \text{ feet per second, velocity of air.}$$

To produce this air velocity, an air pressure of $\frac{(c_2)^2}{2gv_2} = \frac{(60.3)^2}{(64.4)(13.2)} = 4.27$ pounds per square foot or 0.82 inch of water is needed.

Size of induction tube required

$$= \frac{1200 \times 11.4}{3600 \times 40} = 0.095 \text{ square feet} = 13.7 \text{ square inches,}$$

corresponding to a diameter of 4.2 inches.

Area of gas openings = 1.37 square inches.

Area of opening for air at the ring through which the gas is induced $= \frac{10}{11.4} \times \frac{40}{60.3} \times 13.7 = 8.0$ square inches.

In the above calculation it has been assumed that the induction tube is a plain, cylindrical pipe. Much more effective induction and higher delivery pressures can be obtained if a Venturi-shaped induction tube is used. In that case the Carnot loss does not

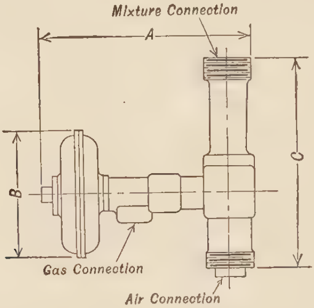


FIG. 48.—Proportions of inspirator in which air induces gas.

Connections			Dimensions			Max. gas capacity of 530 B.t.u. with 1 lb. of air	Max. air required per hour at 1 lb. per square inch pressure
Gas	Air	Mixture	A	B	C		
1″	1″	1″	$11\frac{5}{16}$″	$7\frac{3}{4}$″	$7\frac{1}{2}$″	258	1,120
1″	$1\frac{1}{2}$″	$1\frac{1}{2}$″	$11\frac{7}{8}$″	$7\frac{3}{4}$″	$9\frac{1}{2}$″	560	2,550
$1\frac{1}{2}$″	2″	2″	$13\frac{3}{8}$″	$9\frac{1}{4}$″	$13\frac{7}{16}$″	1200	5,400
$1\frac{1}{2}$″	$2\frac{1}{2}$″	$2\frac{1}{2}$″	$13\frac{3}{4}$″	$9\frac{1}{4}$″	$15\frac{1}{8}$″	1840	8,300
$2\frac{1}{2}$″	3″	3″	$16\frac{1}{2}$″	$13\frac{3}{4}$″	$17\frac{13}{16}$″	2550	11,400
$2\frac{1}{2}$″	4″	4″	$19\frac{3}{8}$″	$13\frac{3}{4}$″	2′ $1\frac{7}{8}$″	4320	19,400
$2\frac{1}{2}$″	5″ Fl'g	5″ Fl'g	$22\frac{1}{4}$″	$13\frac{3}{4}$″	2′ $8\frac{3}{16}$″	7240	31,500

occur; there is only the much smaller loss due to friction at the walls of the tube, and reconversion of velocity or kinetic energy is, therefore, very much more complete.[3]

No type of injector or induction apparatus is entirely self-regulating, as regards maintaining a constant ratio of air to gas in the mixture. Usually, if properly adjusted for an average rate of flow, the injector will supply an excess of air at smaller rates, and a deficiency of air at the higher rates of flow. The methods

[3] Bureau of Standards, Technologic Paper No. 193, "Design of Atmospheric Gas Burners."

and apparatus for maintaining a constant air-gas ratio are discussed in Chapter IV.

As previously stated, the size of gas burners depends somewhat upon the equipment for moving gas and air. For inspirator burners, the relations between sizes and capacities may be taken from Figs. 48 and 49. The caption furnishes the necessary

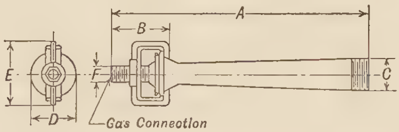


FIG. 49.—Capacities of inspirator in which gas induces air.

Principal dimensions						Maximum gas capacity when supplying furnace		
						City gas, 530 B.t.u.	Water gas, 288 B.t.u.	Producer gas, 150 B.t.u.
						Air gas ratio 4.5	Air gas ratio 2.1	Air gas ratio 1.5
A	B	C	D	E	F	Gas press. 10 lbs.	Gas press. 7 lbs.	Gas press. 1 lb.
$10\frac{5}{8}''$	$3\frac{3}{8}''$	$1''$	$1\frac{3}{4}''$	$3\frac{1}{4}''$	$\frac{3}{8}''$	220	450	...
$11\frac{1}{2}''$	$4\frac{1}{4}''$	$1''$	$1\frac{3}{4}''$	$3\frac{1}{4}''$	$\frac{3}{4}''$	...	...	340
$12\frac{5}{8}''$	$3\frac{3}{8}''$	$1\frac{1}{4}''$	$2\frac{1}{8}''$	$3\frac{1}{2}''$	$\frac{1}{2}''$	320	650	...
$13\frac{1}{2}''$	$4\frac{1}{4}''$	$1\frac{1}{4}''$	$2\frac{1}{8}''$	$3\frac{1}{2}''$	$\frac{3}{4}''$	...	...	480
$14\frac{5}{8}''$	$3\frac{1}{2}''$	$1\frac{1}{2}''$	$2\frac{9}{16}''$	$4\frac{1}{8}''$	$\frac{1}{2}''$	460	925	...
$15\frac{1}{2}''$	$4\frac{3}{8}''$	$1\frac{1}{2}''$	$2\frac{9}{16}''$	$4\frac{1}{8}''$	$1''$	...	...	700
$17\frac{7}{8}''$	$4\frac{3}{4}''$	$2''$	$2\frac{15}{16}'$	$5\frac{1}{2}''$	$\frac{3}{4}''$	700	1400	....
$18\frac{3}{4}''$	$5\frac{5}{8}''$	$2''$	$2\frac{15}{16}''$	$5\frac{1}{2}''$	$1''$	....	....	1070
$22\frac{1}{4}''$	$4\frac{5}{8}''$	$2\frac{1}{2}''$	$3\frac{7}{8}''$	$6\frac{1}{2}''$	$\frac{3}{4}''$	1000	2000	....
$23\frac{1}{4}''$	$5\frac{1}{2}''$	$2\frac{1}{2}''$	$3\frac{7}{8}''$	$6\frac{1}{2}''$	$1\frac{1}{4}''$	....	....	1550
$25\frac{3}{8}''$	$5''$	$3''$	$4\frac{1}{4}''$	$6\frac{3}{4}''$	$\frac{3}{4}''$	1650	3250	....
$26\frac{1}{4}''$	$6\frac{7}{8}''$	$3''$	$4\frac{1}{4}''$	$6\frac{3}{4}'$	$1\frac{1}{2}''$	....	....	2500
$29\frac{1}{4}''$	$5''$	$3\frac{1}{2}''$	$5\frac{1}{16}''$	$7\frac{3}{8}''$	$1''$	2300	4600	....
$30\frac{1}{8}''$	$6\frac{7}{8}''$	$3\frac{1}{2}''$	$5\frac{1}{16}''$	$7\frac{3}{8}''$	$1\frac{1}{2}''$	....	....	3400
$33\frac{1}{4}''$	$5''$	$4''$	$6''$	$8\frac{1}{2}''$	$1''$	3300	6600	....
$34\frac{1}{8}''$	$6\frac{7}{8}''$	$4''$	$6''$	$8\frac{1}{2}''$	$2''$	....	....	5000

information. There are now several types of inspirators on the market, but the dimensions for a given capacity are nearly alike.

The sizes and capacities of fans delivering a mixture of air and gas to the burner nozzles may be taken from Fig. 50, which refers to fans generating a comparatively low pressure. If freedom from danger of back-firing is demanded under all conditions of operation, higher pressures of mixture must be generated. For details see Chapter IV.

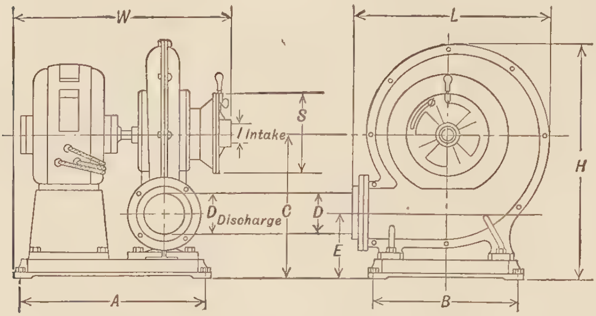


FIG. 50.—Capacities of low-pressure fans for premixing gas and air. Some intermediate sizes were omitted for the sake of brevity.

Gas burning capacity cubic feet per hour	600 B.t.u. mfg. gas	Max.	150	750	2600	8300	15,100
		Min.	50	225	550	2400	5,000
	1000 B.t.u. nat. gas	Max.	100	500	1800	5300	9,600
		Min.	30	125	400	1600	3,000
Pressure—inches of water			2	3	4.5	5.7	9
Cubic feet free air per minute			16	95	300	970	1,765
"A" in inches			$10\frac{1}{4}$	$10\frac{3}{4}$	$16\frac{5}{8}$	$21\frac{1}{2}$	$28\frac{7}{8}$
"B" in inches			$6\frac{3}{4}$	9	$13\frac{7}{8}$	$17\frac{1}{2}$	$22\frac{1}{4}$
"C" in inches			$6\frac{1}{4}$	$8\frac{1}{4}$	$12\frac{1}{8}$	$14\frac{7}{8}$	$18\frac{5}{8}$
"D" for standard pipe thread			1	2	4	5	6
"E" in inches			$2\frac{3}{4}$	$3\frac{9}{16}$	$5\frac{3}{8}$	$6\frac{15}{16}$	9
"H" in inches			$11\frac{1}{2}$	$14\frac{3}{4}$	$20\frac{1}{8}$	$24\frac{3}{16}$	$30\frac{7}{8}$
"I" for standard pipe thread			$\frac{1}{2}$	1	$1\frac{1}{2}$	2	3
"L" in inches			$10\frac{5}{16}$	$14\frac{1}{4}$	$17\frac{3}{8}$	20	$25\frac{9}{16}$
"S" in inches			$4\frac{1}{2}$	$7\frac{1}{8}$	$8\frac{7}{8}$	$12\frac{1}{2}$	$17\frac{3}{4}$
"W" in inches			$12\frac{7}{16}$	$14\frac{3}{16}$	$19\frac{3}{8}$	$26\frac{3}{8}$	$33\frac{3}{8}$
Motor H. P.			$\frac{1}{10}$	$\frac{1}{8}$	$\frac{3}{4}$–$\frac{1}{2}$	2	5

NOTE.—Capacities increased by utilizing secondary air when feasible.

COMBUSTION DEVICES FOR LIQUID FUEL

Preparation of Fuel for Combustion.—Oil or tar never burns as a liquid; invariably it is the oil or tar vapor which burns, because the kindling temperature of the liquid lies far above its vaporization temperature.[4] If an attempt is made to burn liquid oil, the vapor of the oil burns at the surface just as fast as it can combine with the available oxygen. The combustion is then a surface action. If, on the other hand, an oil vapor is formed, and is mixed with air, combustion is a mass action.

[4] It has been claimed that in "flame throwers," finely atomized oil burns as a liquid; but that claim cannot be substantiated. Radiation within the flame causes vaporization, and it is the oil vapor which burns.

Tar, and most of the fuel oils, contain residues which do not vaporize. If these sooty residues, during the process of combustion of the fuel vapor, come into contact with comparatively cool solid walls, they stick to them, forming coke deposits which must be removed at regular intervals, if operation is to continue without interruption.

Quick combustion, completed before the partially burned products have a chance to come in contact with solid walls, is secured by very fine subdivision of the fuel, and quick, thorough mixing of fuel vapor and air. Combustion is quickened still more if the combustion air is highly preheated.

Since only the vapor of liquid fuels burns, it is necessary to prepare the liquids for combustion. There are three methods of doing this, viz.:

(1) Vaporization.
(2) Atomization.
(3) Combination of vaporization and atomization.

Vaporizers.—Method (1), vaporization, may be subdivided into vaporization (*a*) in the furnace, and (*b*) in a separate vaporizer. Method (*a*), which is diagrammatically shown in Fig. 51, can be used successfully with highly preheated air only, because the residual carbon does not burn in cold air. The hot air comes from a recuperator or a regenerator. When a furnace starts from a cold condition a drip burner, such as shown in Fig. 51, produces vast quantities of black smoke and wastes much fuel. Besides, the time required for bringing the furnace up to temperature is very long unless heat is supplied from other sources, such as a wood fire or a special blow torch.

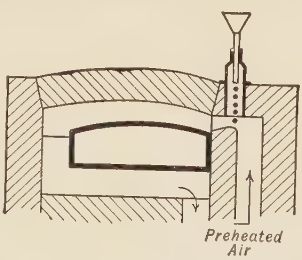


Fig. 51.—Drip or drooling burner, for use with highly preheated air.*

* Reproduced from a German publication on oil burning.

The drooling type of burner is, for these various reasons, useful for a few types of furnaces only, and particularly for those which can be kept in operation without interruption. That type of burner is, therefore, used but little for industrial furnaces. For very heavy Mexican oils the drip type of burner has been used successfully in connection with large tile recuperators which

furnish preheated air at a temperature in excess of 1200° F. The number of installations using this combination will, however, be quite limited.

Method (*b*), namely, vaporization in a separate vaporizer, is likewise quite simple, but it has very great disadvantages, at least in its common embodiment. While vaporization takes place by the heat of the furnace when the latter is in steady operation, an auxiliary heating device is necessary for starting. Furthermore, liquid fuels, with the exception of light distillates, leave residues during vaporization, which means that the vaporizers must be cleaned once a day. For regular industrial furnaces, vaporizer-burners are not used, first, because of the cost of cleaning, and, second, because the control is poor. In Europe, where labor is cheap, vaporizer-burners are in use for intermittent operation of furnaces in localities where gas is not available. (See Essich, Die Oelfeuerungstechnik.)

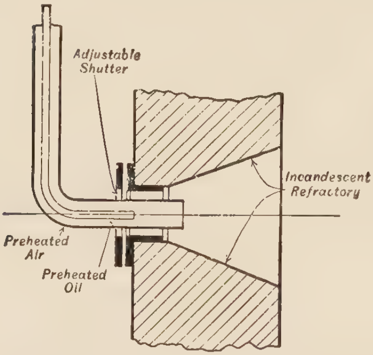


FIG. 52.—Vaporizing burner, for use with highly heated oil and air.

Under certain conditions a combination of methods (1) (*a*) and (1) (*b*) has been fairly successful for furnaces which work continuously. A so-called "burner" involving the combination method is illustrated in Fig. 52. In this device oil is heated by air to a temperature of 400° to 550° F. The stream of hot oil, partly vaporized, and partly ready to flash into vapor, flows into a current of very hot air. The mixture flows through an ignition tile into a combustion chamber which is surrounded with glowing refractories and in which vaporization, as well as combustion, is completed. The combustion method illustrated by Fig. 52 has some advantages, but also has very serious disadvantages. At the time of starting with a cold furnace there is no vaporization, and the heating is slow, smoky, and inefficient. Overheating of the oil in the delivery tube causes carbonization and clogging. The simplicity is tempting, but the difficulties of operation are such that the design has disappeared from the American market.

However, it will probably bob up again in the future as a brand-new invention.

In the United States a vaporizer has recently been introduced in which the heat for vaporization is generated by combustion of 3 to 5 per cent of the oil. Both oil and air enter the vaporizer with a pressure of $1\frac{1}{2}$ pounds per square inch. The mixture impinges upon white-hot serrated ribbons, which quicken the combustion. Vaporization takes place before the oil drops have had time to break up into lighter hydrocarbons and soot. The resulting oil gas passes to the furnace through a short pipe and is burned like a gas. The apparatus is easily regulated during the heating-up period by means of a simple hand control.

Atomization.—Practically all of the important burners on the market are based on "atomization," or, as it is sometimes called in British literature, "pulverization." These terms signify a fine subdivision or spraying of the oil or tar. It must be understood that atomization is only a means of quick vaporization and quick mixing of fuel vapor with air, before the carbon particles have a chance to come in contact with solids. Atomization is followed by vaporization and mixing with air, the third step being combustion. The three steps, (1) atomization, (2) vaporization and mixing, and (3) combustion, overlap to such an extent that no sharp division can be drawn between them, but they are physical realities, nevertheless.

After the oil has left the spray tip of an atomizer, which breaks it up into very small droplets, it enters a burner tile and passes from there into the combustion chamber. The burner tile receives radiant heat from the combustion chamber, and vaporizes the oil. The fractions with the lowest boiling points are driven off first and are burned. They are followed by those with successively higher boiling points. Finally, such a temperature is reached that every drop has been completely vaporized, or the remainder has been broken up into the elements, carbon and hydrogen. The combustion of these elements completes the burning of the liquid fuel. The time required for this process depends upon the rapidity of vaporization and air admixture, and that depends, in part at least, upon the rate at which each droplet absorbs heat. Everything else being equal, the smaller the drop, the quicker the vaporization; from this statement it follows that atomization is a vital factor in the efficient burning of oil or tar,

particularly if only a limited space is available for combustion. The heavier the fuel, the greater is the importance of atomization.

On account of the importance of a thorough understanding of the physical facts in the combustion of liquid fuel, Fig. 53 is offered. The upper part represents, in a diagrammatic fashion, the burner and burner tile, while the lower part indicates velocities. Going from left to right we find increasing velocities of flame propagation (due to better mixture and higher temperature) and decreasing velocities of flow (due to the cone angle of the burner tile). At the point of intersection of the two velocities, combustion begins. It is not necessary to know exactly what the velocity of flame propagation is; the flaring of the burner tile takes care of variations and does it very well. For this, and other reasons, the flaring burner tile has some advantages over the cylindrical burner tile. (See Fig. 54.) In the latter there are eddy currents which, when the furnace is cold, mix cold products of combustion with fuel-air mixture and cause fluttering combustion or even blowing out of the flame. Moreover, the cylindrical tile does not offer

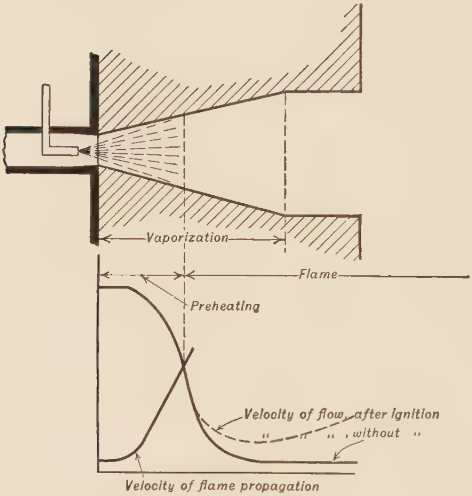


FIG. 53.—Variation of velocities in a burner tile. Note that combustion begins where velocity of flame propagation equals velocity of air-and-oil mixture.

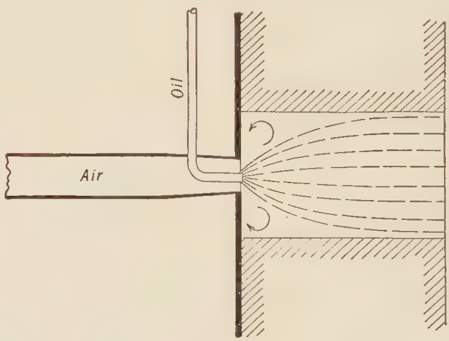


FIG. 54.—Eddy currents in a cylindrical passage in a burner tile.

a definite place at which ignition begins. Cylindrical burner tiles also cause difficulties in starting.

Occasionally a refractory tip (1) (Fig. 55) is arranged in the burner tile, so that the flame may play against it. This tip is very useful when the flow of oil and of air is pulsating, because in that case the flame is easily extinguished unless there is a redhot object directly in the path of the oil and air mixture. Refractory blocks (for splitting the flame) in front of the burner, as indicated in Fig. 56,[5] serve the same purpose. Pulsation is caused by reciprocating oil pumps without air cushioning, or by positive displacement compressors and blowers. (It may even occur, at times, with certain types of turbo-blowers.)

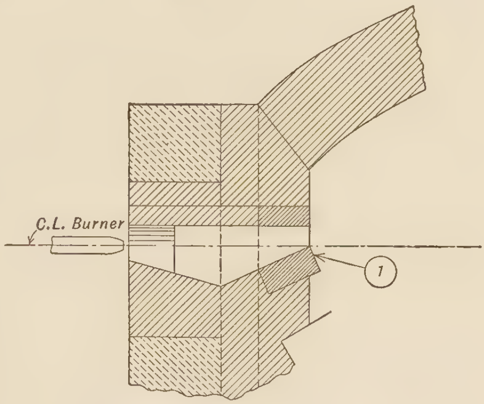


FIG. 55.—Burner opening with refractory ignition tip.

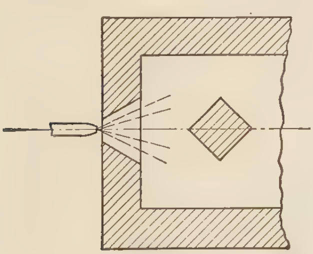


FIG. 56.—Plan view of refractory block in path of flame, for insuring ignition and for spreading the gases more uniformly.

With steady flow of oil and air these devices are not needed. The tip in Fig. 55 has the effect, however, of deflecting the flame from the stock or charge and of directing it toward the roof. This is an advantage in low furnaces equipped with poorly mixing burners. The tip of Fig. 55 causes an undesirable restriction which should be compensated by widening the ignition channel at right angles to the plane

[5] Ignition blocks such as shown in Fig. 56 are frequently used for breaking up the kinetic energy of the products of combustion and for distributing the heat flow throughout the furnace more evenly than it would be distributed without the blocks. Locating the blocks for that purpose is quite an art.

of the paper. No carbon is deposited on the tip. The scouring action of the gases keeps it clean.

In the atomization of a liquid fuel, mechanical work is required to overcome the cohesion, or molecular attraction, of the liquid. Although the amount of this work is unknown, it certainly has some relation to the viscosity and the vapor pressure of the oil or tar. At the vaporization temperature, the cohesion is zero. From this reasoning it follows that liquid fuels should be heated as high as considerations of safety and correct burner operation permit. Tar is heated to 160° or 170° F.; at higher temperatures the more volatile portions of the tar flash into flame, and, moreover, the flame sputters. Heavy oils are heated up to 180° F.; higher temperatures cause too much carbon to be deposited. Lower temperatures are suitable for lighter oils; an oil of 36° to 40° Baumé can be atomized very well at room temperature. If the oil temperature is too high, the lighter constituents of the oil flash into vapor in the burner mouth, where the pressure is reduced, and produce irregular sputtering of the flame.

Atomization is accomplished by two methods:

(1) "Pressure" atomization, in which the liquid is placed under pressure and forced through a small orifice.

(2) "Swift current" atomization, in which the liquid is shredded or sliced by steam or air passing over it at very high velocity.

In atomization by fuel pressure (which is commonly referred to as mechanical atomization) the work of atomization is done by the pressure energy of the liquid fuel; while in steam or air atomization, the work is performed by the kinetic energy of the gaseous medium (air or steam). It is interesting to compare the work requirements of the two systems. Although we do not know the actual amount of work required to overcome the forces of cohesion, we can obtain comparative figures.

Practically perfect atomization can be obtained with an oil pressure of about 120 pounds per square inch. To atomize one cubic inch of fuel requires 120 pounds per square inch times one cubic inch, or 120 inch-pounds, or 10 foot-pounds. Occasionally, higher oil pressures are used. The higher the pressure, the better the atomization.

If atomization is accomplished by low-pressure air, the lighter oils can be atomized with an air pressure equal to 6 inches of water, if at least one-half of the total combustion air is used for atomization. Since one volume of oil requires approximately 10,000 volumes of air, the atomization work, per cubic inch of oil, equals 5000 cubic inches times 6 inches of water times 0.036 pound per square inch per inch of water, or 1100 inch-pounds, or approximately 100 foot-pounds.

If oil is atomized by compressed air or steam a very low figure for the quantity of air used is one-third of a pound of air per pound of fuel. Since one cubic inch of oil weighs 0.03 pound, the weight of compressed air per cubic inch of oil equals 0.01 pound. The minimum power requirement for compressed air is $pv \times \log_e$ (ratio), where: p equals absolute pressure of air, v equals specific volume at pressure p, and $\log_e$ (ratio) equals the logarithm to the base e of the pressure ratio. If air at 90 pounds per square inch pressure is used, the ratio is $\frac{90+14.5}{14.5}$, which equals 7.2. Then the work in foot-pounds per cubic inch of oil equals

$$0.01 \times 14 \times 14.5 \times 144 \times \log_e 7.2,$$

which equals 575 foot-pounds. If the losses in the compressor are taken into account, the work will exceed 650 foot-pounds.

It is very obvious that pressure atomization (mechanical atomization) requires by far the smallest amount of power, as far as atomization alone is concerned. This advantage of pressure atomization is, however, not as great as would appear from the figures for work requirements. In order to insure a steady supply of uniformly heated oil at all burners, it is necessary to pump from two to five times as much oil as is atomized in unit time; the excess work is dissipated in the regulating valve which returns the oil to the sump. Besides, mixing of oil and combustion air requires power. This phase of the problem will be discussed later on.

Pressure Atomization.—Various forces are used to produce mechanical atomization. They will now be enumerated:

(1) If an oil drop moves with extremely high velocity through comparatively still air, the effect is just the same as if fast-moving air passed over an oil drop;

fine shreds of the oil are torn off the drop by the friction between the air and the oil. Atomization, or formation of an oil fog, results.

(2) If a fine stream passes through a sharp-edged orifice, in a conically enlarging orifice plate, the particle marked (1) in Fig. 57 does not lose its lateral velocity, and a mild amount of atomization results.

(3) If oil is heated under pressure it does not flash into vapor as long as the pressure is greater than the vapor pressure of the oil. In the orifice, the pressure is relieved, vapor is formed, and the oil is scattered by

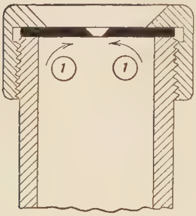


Fig. 57.—Atomizer with simple flat-plate orifice.

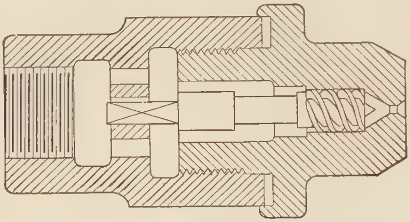


Fig. 58.—Centrifugal atomizer for producing cone.

the "explosion." This action is very effective in producing atomization.

(4) If the oil is given a rotary or whirling motion (for instance, by a screw thread as indicated by Fig. 58), just before it reaches the orifice, each particle has, upon leaving the orifice, a tangential component of motion. In consequence, the oil leaves in a cone-shaped spray, each droplet being torn to pieces, because particles in the same droplet have different tangential directions.

Many combinations of these different actions are possible, and many different types of mechanical atomizers are on the market, particularly for use under steam boilers. For this reason, a detailed description of the various types does not belong in a book on industrial furnaces. There is one very interesting design, however, which must be mentioned, namely, the flat-spray mechanical atomizer. In it the lateral motion of the approaching particles (1), Fig. 57, is accentuated in one direction

and is eliminated in all other directions, by an oblong groove on the approach side. To make room for the flat spray, an oblong groove is also cut into the orifice plate on the delivery side, and at right angles to the groove on the approach side. The action is similar to the production of a flat flame by the impinging of two

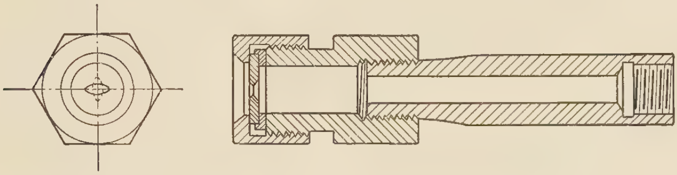


FIG. 59.—Flat-spray atomizer.

jets of acetylene gas. These statements are illustrated by Figs. 59 and 60.

Pressure atomizers have several advantages. Oil piping is needed, in any case, to carry oil to the burner. It may as well be made strong enough and tight enough to sustain sufficient pressure for atomization. No high-pressure air or steam lines are needed. The work (foot-pounds or kilowatt-hours) required for atomizing a given weight of oil with mechanical atomization is less than with any other method.

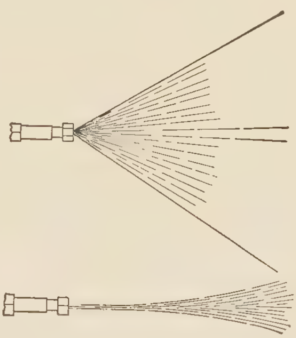


FIG. 60.—Flat spray produced by burner shown in Fig. 59.

Against these advantages must be balanced the following disadvantages: Regulation of the quantity of oil atomized in unit time requires variation of the oil pressure at the orifice, because variations in size of orifice, or exchange of one orifice for another of different size, cannot be accomplished in industrial furnace work. Dropping the pressure to one-half the maximum value lowers the oil quantity, in unit time, to about 70 per cent of the maximum value, and results in less perfect atomization. A second disadvantage, which applies to small unit burners only, is the small size of the orifice. A tip with a $\frac{1}{25}$-inch diameter hole passes 200 pounds of oil (almost 30 gallons) per hour with 200

pounds per sq. inch pressure.[6] A hole of $\frac{1}{50}$-inch diameter passes 50 pounds per hour with the same pressure. But all liquid fuels, such as fuel oil or tar, carry minute solid particles of coke, silt, or slush; and the chances of clogging the burner tip increase rapidly as the size of the orifice is reduced. Care and attention are then required in the installation and maintenance of the oil strainers. For burner tips with very small holes, twin strainers having large capacity and very fine openings should be used, and they should be so designed that they will not be collapsed by the pressure.

Burners with mechanical atomization by high pressure are in successful use on large heating furnaces. The minimum size which can be successfully applied to small furnaces is, as previously mentioned, not a question of burner design, but of strainer design and strainer maintenance. Burners working with high oil pressure require extremely small openings in the regulating valve (needle valve), particularly when the burners pass oil at a reduced rate. Since the needle valve consists of slender cones, the radial width of the annulus between the needle and the seat is extremely small, and clogging occurs frequently, unless very good strainers or "oil-scrubbers" are used in the line.

The many difficulties due to extremely high oil pressure have led to the design of the so-called low-pressure (referring to atomizing air) burners, which effect a compromise and atomize by two actions. The oil is given a primary atomization by being forced through an orifice by a pressure of 30 to 70 pounds per square inch. Atomization is completed by a current of air. Many burners of this type are on the market. Figure 61 represents one example, in which an air pressure equal to that of a 10-inch water column is employed.

Swift Current Atomization.—Atomization by means of steam or compressed air employs two forces: (*a*) the expansive force of the atomizing agent, as it is released from high pressure, and (*b*) the shredding or slicing action which it exerts upon the liquid while the fluid travels at a high velocity. Two systems are in use:

(1) High-pressure atomization.
(2) Low-pressure atomization.

[6] With properly heated oil, the quantity discharged in unit time through an orifice can be computed with sufficient accuracy from the everyday formula of elementary hydraulics, because the viscosity of the oil is too low to affect the result perceptibly.

In the first case, air or steam of 60 to 125 pounds per square inch gage pressure is used; while in the second case, air up to 2 pounds per square inch gage pressure serves the purpose.

An atomizer upon the principle of expansion of oil (or tar)

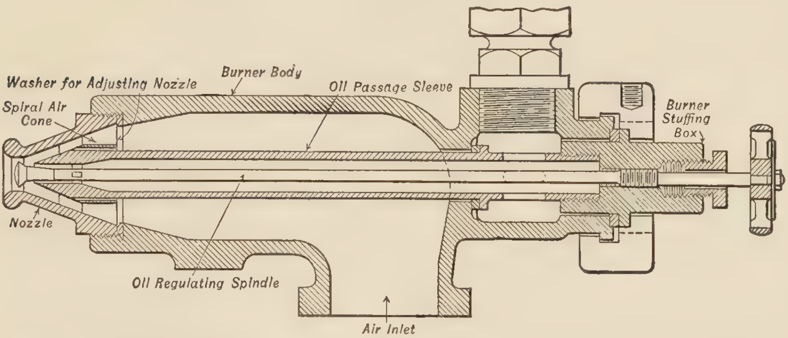


FIG. 61.—Low-pressure burner in which both oil pressure and velocity of air stream are used for atomization.

and steam mixture is shown in Fig. 62. Oil or tar flows through the central pipe, through nozzle (2), and into space (3). Steam or compressed air flows through the annular space (1) and into space (3). The pressures of fuel and of atomizing medium in the supply pipes need not be equal; they are made equal in space (3)

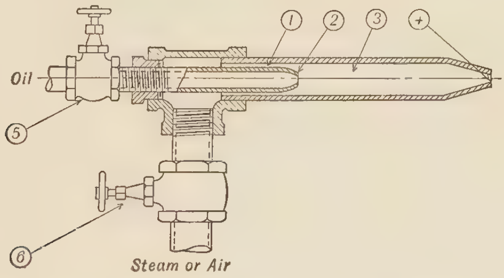


FIG. 62.—High-pressure burner with inside mixing and atomization at tip.

by adjustment of valves (5) and (6). In that space, (3), the pressure is considerably in excess of that of the atmosphere. It drops to atmospheric pressure in the nozzle (4), where the main atomizing action takes place. The great advantage of this atomizer is its simplicity. It is a great favorite for home-made

burners. Its principal disadvantage is the excessive consumption of steam or air, ranging from 60 to 125 per cent of the fuel weight. Besides, the atomization is often imperfect; the fuel drops are large because fuel falls to the bottom of the space (3) and is blown over the edge of the nozzle (4). The latter is frequently flattened for the purpose of obtaining a flat spray. Mixing of oil and steam is somewhat improved by obstructions in the discharge pipe, or by a coil, as shown in Fig. 63. This type of atomizer cannot be generally recommended for industrial furnaces. It is, however, quite satisfactory for open-hearth furnaces because the latter work with highly preheated air, and in addition require a long, luminous flame. It is fairly satisfactory if used on regenerative heating furnaces. In both furnace types,

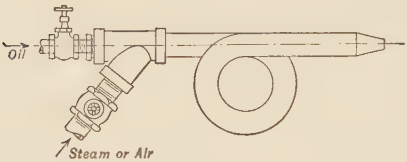


FIG. 63.—Inside-mixing atomizer with mixing loop.

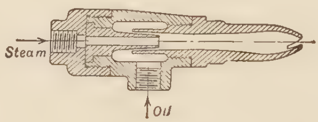


FIG. 64.—High-pressure burner with inside mixing in Venturi throat.

the preheated air evaporates the oil drops and atones for the shortcomings of the atomizer. For those who wish to use the atomizer of Fig. 62, the following remarks are in order: While the main atomizing action takes place in the nozzle (4), the preliminary atomization at point (2) should not be neglected. It can be made effective by letting the oil ooze into the steam space through many small holes in the circumference of the oil pipe, and by letting the steam wipe over them at high velocity. It can also be obtained by using the principle of Fig. 67 (Venturi tube) for the preliminary atomization. Effective mixing exists in the burner illustrated by Fig. 64.

Nozzle (2) should be so proportioned that, for average rate of flow, a pressure of about 30 pounds per square inch exists in space (3). Nozzle (2) should taper gradually, and may well be slightly divergent, following a convergent part.

Oil pressure and steam pressure must be kept quite constant, preferably by sensitive pressure-reducing valves. The slightest variation of either pressure changes the character of the flame

quite noticeably. Pipe lines must be large enough to deliver the full steam pressure and oil pressure at greatest rate of flow.

In atomizers which use steam or air flowing at high velocities it is very important that none of the atomizing fluid be allowed to pass through the atomizer without coming into intimate contact with the fuel drops. This is of the greatest importance with steam, which is a diluent and does not sustain combustion. With air as an atomizing agent, the best utilization of atomizing air is a question of power consumption in all cases, and a question of fuel saving in all those cases in which the greatest possible amount of the combustion air is to be preheated.

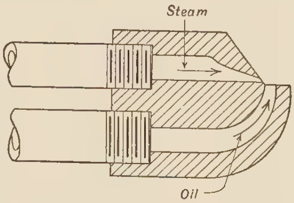


FIG. 65.—High-pressure burner producing a flat flame.

There is no exaggeration in the statement that there are at least 5000 different air or steam atomizers in existence. It is quite out of the question to describe even 5 per cent of their number here. This chapter is limited to pointing out the guiding

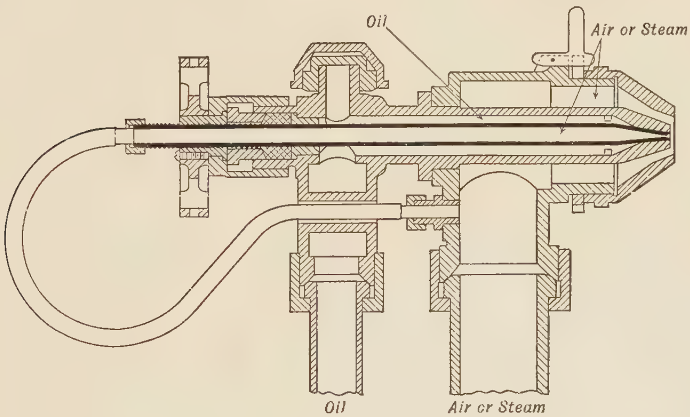


FIG. 66.—Atomizer with air or steam admitted both inside and outside of fuel stream.

principles for prospective users and designers of atomizers, although one might suppose that most new designs of atomizers were only slight modifications of those now in existence.

Fuel and atomizing agents must flow in thin sheets or fine

streams and must meet at a place where the atomizing agent flows at a very high velocity. Examples embodying these principles are shown in Figs. 65, 66, and 67. Figure 65 is a diagrammatic sketch of a well-known atomizer which throws a flat flame. It is a high-prcssure burner, and, like other burners employing high steam pressure, produces a long fan-shaped flame, which requires a long combustion space. Figure 66, which is an old but nevertheless typical design, illustrates the principle of letting the atomizing agent work on the inside and also on the outside of a thin ring of fuel. This principle is a very good one, but the application of it shown in Fig. 66, is open to objection, because the adjustment of the inner air tube is unreliable and uncertain. Figure 67 is a diagrammatic illustration of the principle that very great velocities can be obtained at the throat of a Venturi tube, even at moderate pressures, and that fuel can advantageously be fed into the low-pressure region at the throat, where it is thoroughly pulverized. Very successful atomizers based on this principle are on the market.

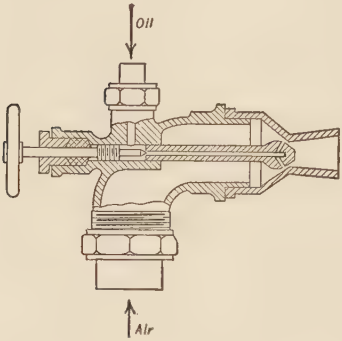


FIG. 67.—Simple form of atomizer with oil admitted at Venturi throat.

Atomization and mixing of oil vapor with air can be effected in stages. The tip of an atomizer using two successive stages is shown in Fig. 68. (See also Fig. 73.)

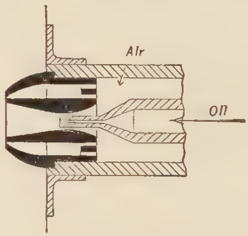


FIG. 68.—Tip of burner in which oil is atomized by air in two stages.

For those obliged to choose between high-pressure and low-pressure atomization, the following reasoning may be helpful. Plants carrying high steam pressure are becoming scarce, because of the increasing use of power transmission by electricity. Besides, steam pipes cause great heat loss by condensation. In consequence, atomization by steam, while very common for boiler furnaces and open-hearth furnaces, is gradually disappear-

ing from industrial furnace practice. Furthermore, steam, as commonly used, produces a long flame and is hard on brickwork. Highly compressed air has certain advantages as an atomizing agent. It sustains combustion, while steam acts as a ballast. A well-designed atomizer, using highly compressed air, can get along with a quantity of compressed air equal to 7 per cent of the total combustion air, leaving 93 per cent to be brought from elsewhere, for instance, from a recuperator or a regenerator. Moreover, the oil can be throttled down considerably without adjustment of the quantity of compressed air, it being assumed that the rest of the combustion air is adjusted accordingly. Low-pressure burners use more air (up to 60 per cent) for atomizing purposes, leaving less to be brought from a recuperator or a regenerator, but, of course, slightly preheated air may be used for atomization. On account of the large fraction of the combustion air which must be used for atomization, adjustment of oil flow also requires adjustment of the flow of atomizing air. This latter adjustment must be accomplished, not by throttling through a valve in the line, but by adjustment of the air orifice at the point where the air impinges upon the oil. This principle is illustrated by Fig. 69. The oil, which oozes out of radial holes, is picked up by a current of air. By an axial adjustment of the nozzle parts, annulus (1), as well as annulus (2), can be adjusted. The velocity of the air (which does the atomizing) can be kept constant in spite of wide variation in the quantity. This burner is of German design; it has too many adjustments to be entrusted to the average furnace attendant. By rights, the adjustment for oil and air should be inter-connected in this burner, because it supplies all the air needed for combustion, and observation of the flame is difficult.

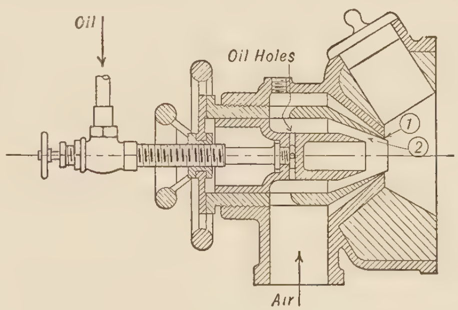


Fig. 69.—Atomizer in which air velocity at the tip is kept constant.

While the burner of Fig. 69 is strictly a low-pressure burner (the pressure of the oil is not depended upon for helping atomiza-

tion), by far the greater number of oil-fired industrial furnaces are equipped with burners which use an oil pressure of 30 to 60 pounds per square inch, and a blast pressure of 7 ounces to 2 pounds. If an oil pressure of 60 pounds per square inch is necessary for good atomization, the burner is almost a " mechanical " (pressure) atomizer, and shares the advantages and the disadvantages of that type. In particular, it requires excellent straining. If an air pressure of 7 ounces is used, all of the combustion air is supplied by a fan. If a pressure of 2 pounds per square

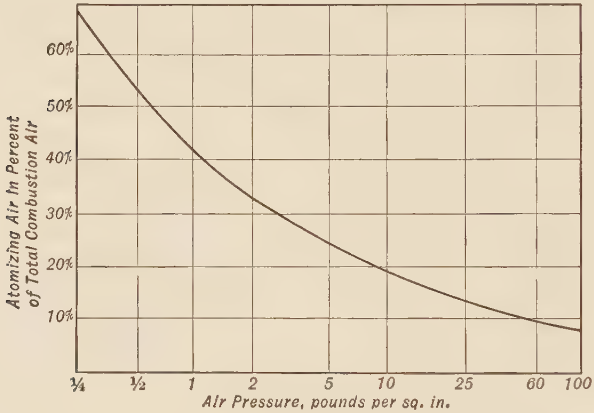


Fig. 70.—Relation between air pressure and quantity of atomizing air required.

The curve shows average values of the minimum amount of air required for good atomization. Greater quantities are frequently used, but the volume cannot be reduced below the minimum except under unusually favorable conditions.

inch is available, only a fraction of the combustion air is supplied by a blower, while a large part of the combustion air is induced.

The quantity of air which is needed for good atomization of a unit quantity of oil varies not only with the air pressure, but also with the design of the atomizer, with the temperature of the oil, with the pressure, and other features. For that reason, Fig. 70, which gives the ratio of atomizing air to total air as a function of the air pressure, is only an average or an approximation. Nevertheless, it shows that with $1\frac{1}{2}$ to 2 pounds per square inch gage pressure of atomizing air, only 30 to 40 per cent of the total air quantity is needed for atomization. Since pressures up to 2 pounds per square inch can readily be produced by positive

blowers or by three-stage turbo-blowers, atomizers for these pressures have become very popular.

Mixing of Oil Vapor and Air.—It has been stated on good authority that there is no such thing as an oil burner, and that equipment bearing that name should be rechristened "oil atomizer," because it serves a purely mechanical purpose, namely, that of atomization. Unfortunately for the art, this is only too true of a very great number of oil burners now on the market. It would be much better if, in addition to atomization, provision were made in these burners for proper mixing of air with the oil mist, and for regulation of the mixture ratio. In more recent types of oil burners, such provision is made, and these can properly be styled oil burners.

The view that the burner alone is all-important, and that, if a good burner is used, the furnace design is unimportant, is of course entirely wrong. On the other hand, it is possible to swing to the other extreme and assume that all burners are equally good, and that furnace design only is of importance. As a matter of fact, there is a great difference in the performance of different oil burners on the same furnace, a fact which is well known to everyone who has operated different types of burners.

The means used for maintaining the correct oil-to-air ratio are discussed in detail in Chapter IV. The means for the proper mixing of atomized liquid fuel and air will now be discussed.

One of the first questions encountered in the problem of mixing atomized liquid fuel and air is this: Can the combustion air be induced, or is blast air required for good mixing and complete combustion? A brief and approximate calculation of the comparative inducing capacities of the different oil-spraying systems will make this point clear. The results of the calculations are given below, in tabular form, one pound of oil forming the unit of reference.

The last vertical column is the most interesting one. It shows the furnace pressure, in inches of water, against which the resulting oil and air mixture can be delivered by induction. The values in that column were found by making certain assumptions, (1) on the efficiency of the conversion of velocity into pressure, (2) on the velocity, and (3) on the specific volume of the air and oil mixture at the entrance to the furnace. In practice, certain variations from these assumptions will occur, with the

result that only a fraction of the calculated pressure can be overcome by induction. However, the figures can at least be compared with each other. It is quite evident that oil-pressure atomization (mechanical atomization) cannot induce any combustion air, and that fan-blast air is required. This requirement tends to equalize the advantages, in the matter of power consumption, of the two methods of atomization, because, while mechanical atomization requires the least power for atomization purposes alone, it necessitates the use of additional power for air delivery (except in the few cases where warm air from regenerators enters by its own buoyancy). However, not all of the combustion air need be delivered by a fan; some of it can be induced. It is also evident from the table that the so-called low-pressure, or positive-pressure atomization, which uses $1\frac{1}{2}$ to 2 pounds per square inch air pressure, can induce air against a higher furnace pressure than the other systems can.

TABLE XI

Method of atomization	Velocity of oil, ft./sec.	Velocity of atomizing air, ft./sec.	Pounds of atomizing air per pound of oil	Weight momentum of oil and atomizing air	Weight of air to be induced, pounds	Velocity of resulting mixture, ft./sec.	Pressure against which air can be induced, inches of water
Mechanical; oil at 150 lbs. per sq. in......	165	0	0	166	14	11	0
High pressure air atomization, 100 lbs. per sq. in...........	....	1600	1.12	1792	12.88	120	1.00*
Low pressure air atomization, 2 lbs. per sq. in...	†	490	4.62	2270	9.38	151	1.70
Fan blast atomization air at 4 oz...........	†	139	9.50	1320	4.50	88	0.11

* The high-pressure burner can induce against a higher pressure, if more than the minimum quantity of air necessary for atomization is used.

† Low pressure burners usually operate with some oil pressure. The resulting oil velocity does not change the calculation appreciably.

In medium-sized and small oil-fired furnaces simplicity is usually valued more highly than the highest possible economy. This fact explains the popularity of the $1\frac{1}{2}$ to 2 pounds-per-square-inch burner with induction of cold combustion air.

The tabulation shows, incidentally, why mechanical atomization is popular for boilers. It requires the least power, and the stack draft brings in the air. Boiler furnaces, in this respect, are quite different from industrial furnaces; in the former there is a slight vacuum, and in the latter, a slight pressure.

After this digression into the realm of induction the discussion of mixing air and oil mist can be resumed. Thorough mixing is comparatively easy with the system of oil pressure (mechanical) atomization, because fan-blast air must be used, and because the fan blast allows the directing of a swift current of air into the very core of the oil mist. A burner embodying this principle is shown in Fig. 71. Without the air blast, the oil sprays in a conical shape; the air blast, directed by the adjustable cap, forces its way to the center of the oil mist and prevents the quick spreading of the cone. The latter then assumes the convergent-divergent shape indicated in the illustration. The blast air may be preheated up to 800° F. or even 900° F. In that case not the slightest trace of flame or oil mist is visible; in its place appears a bluish-violet haze of high-temperature heat. Adjustment of the supply of oil and air in unit time requires either adjustment of the blast pressure by means of a blast gate, or else of the position of the air cap at the mouth of the burner. From the standpoint of thoroughness of mixing, the latter is better, because it maintains the velocity of the blast at the point where it enters the oil mist. On the other hand, adjustment of the cap at the hot burner is not very pleasant, and besides, the opening between the burner cap and tile is varied. By rights, there should be no opening at that place, if hot air is being supplied, because cold air may be induced; but a sleeve should be slipped over the cap so as to make a reasonably tight joint with the burner tile.

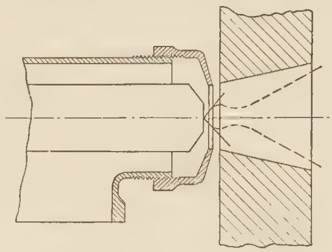


Fig. 71.—Mixing of air and oil mist in pressure atomizer. Note adjustable blast cap.

A very recent design is shown in Fig. 72. Oil with a pressure of at least 25 pounds per square inch is discharged from a tip (3) with a whirler, which by itself would spray the oil in a divergent cone. Air passing through orifice (4) mixes with the oil mist in a manner similar to that of Fig. 71, the mixture taking place in nozzle (5). At the end of the nozzle the jet meets another inwardly directed stream coming from an adjustable space (6) between cone (7) and the burner housing. The blast gate (8) is not used for adjustments, but only as a complete shut-off. Oil regulation is accomplished by handwheel (1), and air regulation by handwheel (2). The burner is characteristic of many so-called "low-pressure" burners. The air pressure ranges between 7 and 16

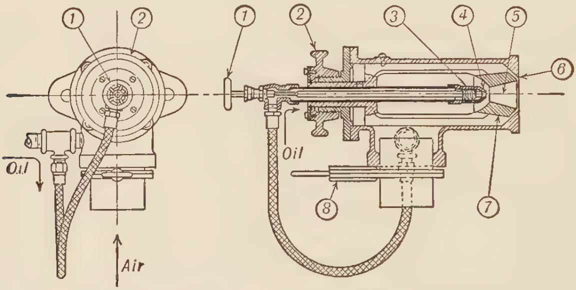


Fig. 72.—Burner with double air cone and air adjustment at the tip. Air velocity is kept constant at the outlet.

ounces per square inch, but atomization would be extremely poor if it were not for the oil pressure.

In contradistinction to the burners shown in Figs. 71 and 72 the one shown in Fig. 73 is a true low-pressure burner and is, in that respect, similar to the one shown in Fig. 69. It is mentioned at this place on account of the air-admission control features which it possesses. It will be noticed that tar enters into a narrow annulus (1) which surrounds sleeve (2), and from there passes through adjustable slots (4) radially into an axially flowing current of air. It should be noted that these slots are of fair size, and that the liquid fuel oozes out at comparatively low velocity.[7] After a short travel the mixture impinges upon the central core of

[7] If the velocity is too low, most of the fuel oozes out at the bottom, and the top slots remain dry.

air. It finally meets another annular jet of air at the point of leaving the burner. Twisting of the handle adjusts the fuel openings, and simultaneously, by longitudinal shifting of the sleeve, two of the air cone openings. Interdependence between

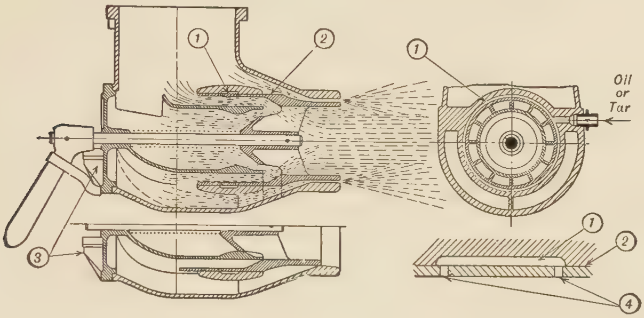


FIG. 73.—Low-pressure burner with triple air admission.

Note that air stream velocities are kept almost constant, and that air and oil adjustments are inter-connected.

air and fuel adjustments is secured by the cam (3) on which the lever slides. In starting up, the air is automatically turned on first, and in shutting down, the fuel openings are closed first. By means of a three-way valve, the tar passages can be blown out during operation, with compressed air, whereby sticking or clogging is prevented.

With burners which induce air the mixing must necessarily be slower. Length of path of air and oil vapor make up for the deficiency. This fact was recognized quite early in the history of the art of oil burning, and extension caps, as indicated in Fig. 74, were provided. These caps were made of cast iron and were lined with refractory material. They served very well and are a logical design; but, in spite of this fact, they were abandoned by many builders because they project beyond the furnace, and, together with the burner equipment, take up room outside of the

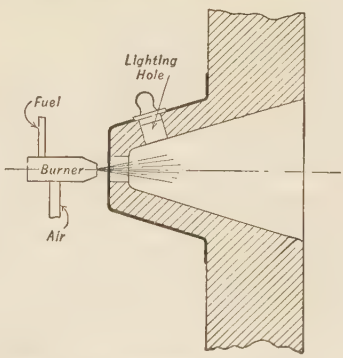


FIG. 74.—Extension cap for oil burner.

furnace. In several designs, their place has been taken by thick walls with burner tiles, such as those indicated in Fig. 55, particularly with the low-pressure ($1\frac{1}{2}$ to 2 pounds per square inch) burner, using not only "swift current" atomization, but also some mechanical atomization. (Most oil burner manufacturers recommend that the oil be delivered to the burners with a pressure of 25 to 60 pounds per square inch.) Atomization is better now than it was in the earlier days, and only a fraction of the air need be induced with the low-pressure system. The deflecting effect of the tip causes a secondary mixing, and guides the flame along the roof, where it burns before striking the stock or charge. Thus it is possible to get along without the combustion chamber.

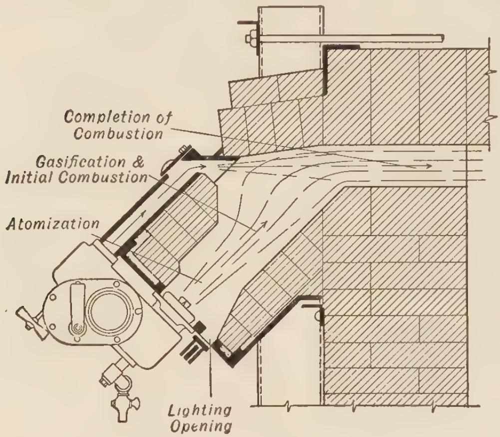


FIG. 75.—Gasification chamber for oil burning.

On the other hand, the extension cap is coming back in a modified form, as "calorizer," or "accelerator" (see Figs. 75 and 76). Oil vapor and some air are allowed to mix in an "ante-room," and are then blown into the furnace with a sudden change of direction, which, of course, can be furnished only by blast air. These designs result in excellent combustion, but the walls of the preliminary combustion

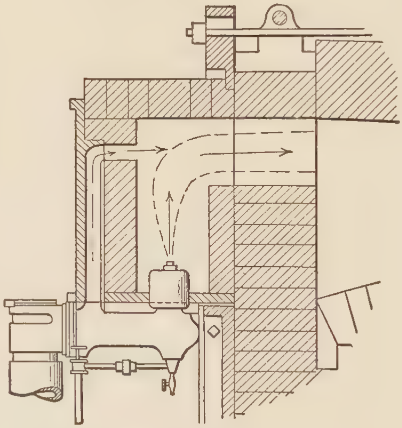


FIG. 76.—Gasification chamber for oil burning, with vertical burner. Air and oil vapor meet at right angles.

chamber burn out unless great care is used in the adjustment of primary and secondary air.

Mixing of air and oil vapor in the burner tile, by giving the air a helical motion, is not generally practiced. A small amount of this action may be had by putting screw vanes into the air register. In burners which carry a thin, ring-shaped film of oil between an outer and an inner current of air, helical vanes in the inner pipe are advantageous, because they whirl the core of air and cause it to spread through the oil film. For adjustment of the nature of the flame (air-to-oil ratio) an air register is usually provided, as indicated in Fig. 77. Helical vanes (1) in such a register will do good only if the oil spray leaves the tip in a wide-angled cone. If the cone angle of the oil mist is narrow, the guide vanes do more harm than good, because they whirl the air against the outer circumference of the burner tile, instead of forcing it into the core of the oil mist. Occasionally, a sharp edge is provided in front of the atomizer. It splits the oil mist and throws it to both sides into the air current.

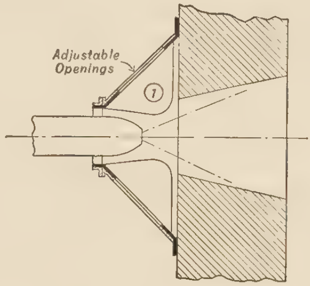


FIG. 77.—Air register with helical vanes, for oil burner.

Capacity of Oil Burners.—It is often required to ascertain approximately the capacity of a given oil burner, or to design a burner for a given capacity. The method of making these calculations is shown in the following example.

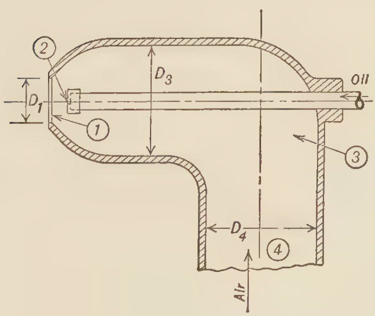


FIG. 78.—Diagram of simple form of low-pressure burner.

An oil burner is to have a capacity of 10 gallons of oil per hour at 40 to 50 pounds per square inch oil pressure, 12 ounces per square inch air pressure. What size of air nozzle, of air inlet, and of oil openings are required?

For the purpose of this example a very simple and idealized type of burner will be considered, as shown diagrammatically in Fig. 78. This should not

be taken as representing best practice in burner design. In many of the more developed types, for instance, air would probably be admitted inside as well as outside the oil spray. The burner shown in Fig. 78 was selected for this example on account of its simplicity. The same principles of calculation apply, of course, to the more complicated burners.

For a low-pressure burner using air at 12 ounces pressure about 70 per cent of the quantity of air ideally required for combustion is usually supplied at this pressure, the remainder being induced from the atmosphere.

Total air required

$$=\frac{10 \text{ gal./hr.}\times 6.75 \text{ lbs./gal.}\times 14 \text{ lbs. air/lb. oil}\times 13.2 \text{ cu. ft./lb. air}}{60 \text{ min./hr.}}$$

$=209$ cu. ft./minute, if no excess air is supplied.

$70\%\times 209$ cu. ft./minute $=147$ cu. ft. free air/minute required at 12 ounces pressure.

The velocity of air at ordinary temperatures, corresponding to a pressure drop of 12 ounces per square inch, is approximately

$$c=\sqrt{64.4\times\frac{12 \text{ oz.}}{16 \text{ oz./lb.}}\times 144\times 13.2} \text{ specific volume}$$

$$=303 \text{ feet per second.}$$

On account of the shape of the nozzle usually employed in oil burners, the air jet will contract somewhat, giving a discharge coefficient of about 0.85.

Then

$$0.85\times A_1\times 303=\frac{147}{60} \text{ cu. ft. per sec.} \quad \text{Solve for } A_1.$$

$A_1=0.0095$ square foot, area of outlet,

and

$D_1=1.32$ inches, or approximately $1\frac{5}{16}$ inches, diameter of nozzle opening.

With oil heated sufficiently for atomization, the viscosity is too low to affect the flow through orifices to a noticeable extent. Assuming the flow to be reduced even as much as 10 per cent below that of a perfect fluid, the size of the oil hole (2) is found from the equation:

$$\frac{10 \text{ gal./hr.}}{60\times 60\times 7.48 \text{ gal./cu. ft.}}=\frac{A_2}{144}\times 0.90\times 0.62\sqrt{\frac{45 \text{ lb./sq. in.}\times 64.4\times 144}{50 \text{ lb. oil/cu. ft.}}}.$$

$A_2 = 0.00105$ square inch

$d_2 = 0.0365$ inch, diameter of oil opening.

Next, suppose that $\frac{1}{2}$ ounce air-pressure drop is allowed, to take care of the resistance of the right-angle bend at (3) and velocity head at entrance (4). The bend resistance is approximately equal to the velocity head, hence each is $\frac{1}{4}$ ounce.

$$\text{Velocity corresponding} = \sqrt{64.4 \times (\tfrac{1}{4} \times \tfrac{144}{16}) \times 12.5}$$
$$= 43 \text{ feet per second.}$$

(12.5 = specific volume of air at 62° F. and 12 ounces air pressure)

$$A_4 = \frac{\frac{12.5}{13.2} \times 147 \text{ cu. ft./min.} \times 144}{60 \times 43 \text{ ft./sec.}} = 7.8 \text{ square inches.}$$

$D_4 = 3.15$ inches.

A standard 3-inch pipe could be used, giving a slightly greater loss, $\frac{5}{8}$ ounce per square inch, instead of $\frac{1}{2}$ ounce per square inch.

The calculation shows clearly that the dimensions of the burner are determined, not by the size of the oil openings, but by the size of the air passages. The overall size of the burner shown is determined by the diameter D_4. If it were desired to use this burner for twice the quantity of oil, a new tip could easily be placed on the oil tube, with an aperture of twice the area, but the air opening could not be appreciably increased without providing an entire new casing. On the other hand, if the air required for the double quantity of oil were to be forced through a $1\frac{5}{16}$-inch diameter opening, the pressure required would be 48 ounces, or 3 pounds per square inch, which is excessive. Furthermore, the velocity would be too great, and would blow the flame away from the burner.

Again, if the air were preheated to 400° F., the air outlet diameter (for 10 gallons of oil per hour) would have to be increased to $1\frac{5}{8}$ inch, if the same pressure of 12 ounces per square inch were used.

Of course, where higher injection pressures and velocities are used, a somewhat smaller proportion of the total air is required to be supplied through the nozzle, but this difference is not enough to affect the figures appreciably.

On the other hand, on account of the drooping characteristic curve of the fan or blower, as the quantity of air being supplied by the latter increases, the pressure drops off. This means that when more pressure is needed at the burner, less is available at the fan. The maximum air flow through the burner is, therefore, sharply limited, unless a high-pressure blower is used and the pressure at average rates of flow is reduced by throttling, which results in a waste of power.

In summary, then, the dimensions of an oil burner are determined not by the quantity of oil, but by the quantity of air which it must supply, and a given size of burner cannot be used satisfactorily to burn a greater quantity of oil than that corresponding to the quantity of air which it will supply under the pressure for which it was designed.

Troubles with Oil Burners.—One of the most troublesome features of burners for liquid fuel is carbonization (coking) of the fuel in the burner, and clogging caused by it. This is due, in a large measure, to the fact that the burner tip is at all times exposed to the radiant heat of the combustion chamber. If preheated air is used, the burner also receives heat from the air-blast pipe, which surrounds the oil pipe. Several methods are in use for minimizing the danger of carbonization: The burner tile is made long and no larger at the air entrance than necessary. Low-pressure burners, which use a large fraction of the necessary air for atomization, are well protected by the constant flow of cold air. Burners with mechanical atomization and with preheated blast air are in greatest danger of carbonization, particularly at light loads. In burners of that type it is customary to surround the oil pipe (1), Fig. 79, with an insulating jacket (2), through which circulation of atmospheric air takes place or a small flow of compressed air is maintained. This air is discharged at the tip. A burner with a supply of cold air and of preheated air is illustrated in Fig. 80. The oil supply is everywhere surrounded by cold air. Furthermore, the oil is never

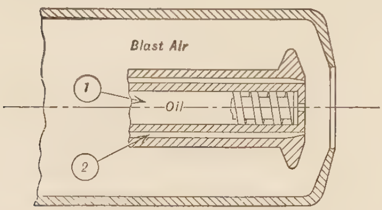


Fig. 79.—Burner for use with preheated air.

Note insulating jacket of cold air around oil tube.

stagnant in the burner, but flows through to the return pipe at all times.

The most serious coking of the oil occurs when the burner is not in use. The radiant heat of the furnace is then transmitted back to the body of the burner, and cokes whatever oil or tar happens to be in it. For that reason it is customary to provide connections for blast air or for compressed air, these connections being so arranged that the oil remaining in the burner can be blown out. It is also necessary to use tight oil valves, because even a small supply of oil or tar dripping into the hot end of the burner cokes and becomes so hard that it must be chiseled

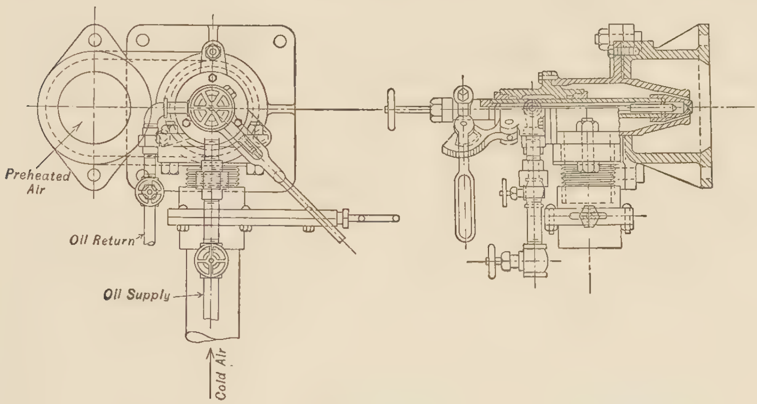


Fig. 80.—Oil burner for preheated air. Oil tube is surrounded by cold air. Recirculating system forces oil to flow through burner continually.

out. This feature is so troublesome that some engineers prefer to put two shut-off valves in series, hoping that at least one of them will hold. It is a customary rule to arrange oil or tar burners horizontally or nearly so, although for some purposes it would be more convenient to fire vertically upward. This latter arrangement presupposes very perfect atomization so that no oil drops can fall back upon the burner and coke upon its surface.

All combustion devices have shut-off valves and regulating valves. Their proper location offers a difficulty. They should be located quite close to the burner; this statement applies particularly to the fuel valve, because fuel beyond the valve may carbonize if the pipe is too hot, or congeal if the pipe is too cold. On the other hand, the fuel valves and the air valves should be so

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located that a flare-back in starting up does not injure the operator. To combine both requirements is often difficult.

It may be appropriate to call attention to the part which auxiliary equipment plays in oil burning. Oil must be pumped to the burners without pulsations. The pump must be capable of moving very stiff oil, because most of the oil is cold and almost solid after a long shut-down. The oil piping must be free from leaks. It is desirable to have a circulating system, in order that oil may circulate close to each burner, even when all burners are shut off. Long oil lines are usually placed underground to comply with the requirements of fire underwriters. When this is done, they should be placed in a trench which is accessible for inspection. Oil-heating equipment must be provided, preferably with a thermostat for keeping the oil temperature quite constant. Oil strainers, preferably of the twin type, must be used. The oil pressure must be kept constant; in a circulating system, this requirement is met by a relief valve. which must be close to the furnace.

If steam serves as atomizing agent it must be kept absolutely dry and at constant pressure. For the former purpose, steam separators and traps are used; for the latter purpose, suitable pressure-reducing valves are installed. If air is used for atomizing, its pressure must likewise be kept constant by a reducing valve. The air should be free from pulsations. If combustion air is delivered by a fan, the supply must be under control, for instance by blast gates.

The proper selection and installation of auxiliaries for oil burning is a field by itself. It lies somewhat outside the scope of this book.

COMBUSTION DEVICES FOR SOLID FUELS

Principles of Combustion of Solid Fuel on the Grate.—Solid fuels, including coal, coke, wood, and peat, are either burned on a support, such as a plate or a grate, while air is being forced through the fuel, or else they are dried and powdered and are then burned in the form of dust, which is blown into the combustion space.

If a solid fuel is burned on a support it is either charged by hand or else mechanically. In the latter case the device is called a mechanical stoker or, more briefly, a "stoker."

In the following discussion more attention will be given to bituminous coal than to other solid fuels, because it is the most widely used.

The well-known arrangement of the ordinary grate is diagrammatically shown in Fig. 81. Coal burns just as it would on a boiler grate. When the gases leave the fuel bed they are not completely burned, because the hot carbon dioxide, which is formed in the lower layers of the coal bed, is reduced to carbon monoxide in the upper layers. Besides, hydrocarbons are distilled off from that coal which has not yet been coked. Combustion can be made complete by the presence of oxygen above

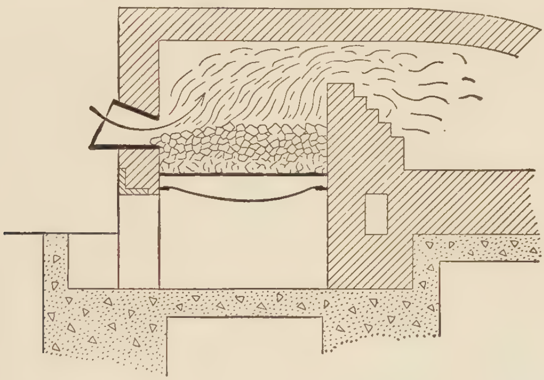

Fig. 81.—Grate and combustion chamber of coal-fired furnace with draft over the hearth.

the fuel bed. If the coal is in the shape of large lumps and does not cake or break up into small pieces in the fire, the air which is necessary for completing combustion above the fuel bed will pass through the air channels formed between the large lumps. Conditions for delivering the necessary air to the combustible gases will then be fairly good; and if the gases are mixed in a narrow throat above a bridgewall, combustion will be 70 to 80 per cent complete before the gases reach the charge resting on the hearth. For that reason, large free-burning lump coal is desirable for this method of firing. If " run of mine " coal is delivered at the furnace, experienced heaters pick up the coal with an open-pronged fork (coke fork) which leaves small pieces and fines behind. If, on the other hand, " run of mine " or small lump coal, or a caking coal

is put on the grate, the air which is needed for combustion above the fire cannot pass up through the coal and must come in through openings above the fuel bed, for instance, through the fire door (see arrow in Fig. 81). In that case, the mixing of the air and combustible gases is very poor and combustion frequently extends into the flues or even into the stack. With a high rate of combustion (50 to 60 pounds of coal per square foot of grate per hour), stack-gas analyses like the following have been observed: 2 per cent CO_2, 11 per cent O_2, 10 per cent CO. This flue-gas composition is indicative of very poor combustion.

Since, in this type of furnace grate, the force for moving the air and gases is furnished solely by stack draft, there must be a draft, that is to say, a partial vacuum, immediately above the fuel bed. If grate and hearth are on the same level, air is drawn in through every crevice and through the openings around the furnace doors. If a metal is heated on the hearth, the loss from scaling is excessively great, the degree of oxidation depending upon the tightness of the furnace structure and upon the care of the heaters. In furnaces with natural draft and with grate and hearth at the same elevation the door frames and sills of the heating chamber are occasionally made to extend outward for 6 inches or more, so that the heaters can pile up coal or coke, ashes or cinders on the outside of the door and thus reduce the air infiltration and oxidation. In other cases, the heaters charge coal inside the door, and this coal, by its combustion, protects the steel from oxidation. This procedure is, of course, more or less of a nuisance. In order to keep the inrush of cold air into the furnace from being excessive, engineers use a large grate in comparison to the hearth area, because, in that case, only a small draft is required to move the air which is necessary for burning the coal. A rating of 15 to 20 pounds per square foot of grate per hour should not be exceeded. It is understood that a fairly thick fuel bed must be used, so as to facilitate the maintaining of a uniform fire.

To adapt the grate to industrial furnace conditions (which require a slight pressure in the heating chamber) one of two things must be done. Either the grate must be located below the level of the hearth, or a pressure must be applied to the air in the ash pit. The former arrangement (which is quite common in sheet furnaces and in coke-fired drying ovens) is indicated by the

sketch Fig. 82. A slight draft may exist immediately above the fuel bed, and yet a very slight pressure will exist on the hearth, on account of the difference in level and of the temperature difference between cool atmospheric air and the hot products of combustion in the combustion chamber. It is immediately evident that this nice balance of pressures presupposes very constant conditions of the fuel bed and rate of combustion, both of which require the services of a skilled and watchful fireman, or " heater." If the vertical distance between the fuel bed and the hearth is

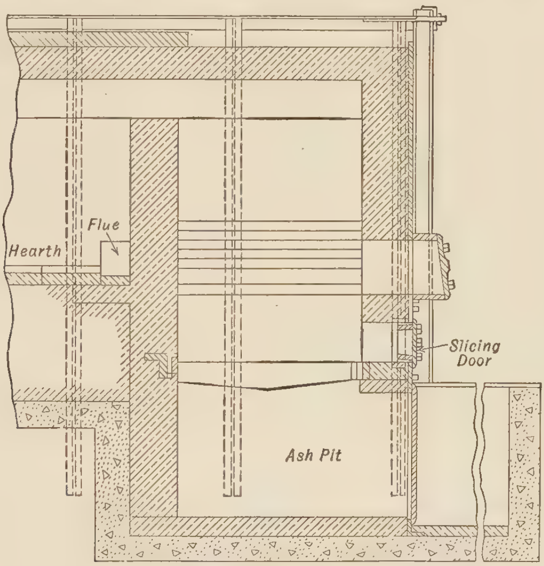

FIG. 82.—Grate located below the level of the hearth.

considerable, secondary air can be blown in above the hearth, and grate firing then passes by degrees into " semi-gas " firing. The result of carrying this thought to a logical conclusion is the furnace with an attached or self-contained producer, as shown in Fig. 83. This type of furnace and producer is more than fifty years old and is quite common in Europe. It is now being revived in the United States. The operation of the producer could be very much improved by an automatic continuous coal feed. The design of the stepped grate used as fuel support in semi-gas producers varies with the kind of coal. The design of the gas

chamber above the grate must likewise be adapted to the fuel. On account of the small use which is made of this type of grate in the United States no detailed description of these designs is given here.

If air is to be blown up through the grate, for instance by a fan, the ash pit must be sealed. While this arrangement does away with the necessity for draft above the fuel bed and thereby prevents infiltration of air and oxidation of the charge on the hearth, it also interferes with combustion, unless air is blown in above the fuel bed also. It is true that the latter procedure is not absolutely necessary, because some air can pass through the fuel bed if good lump coal is used, but the expense and trouble

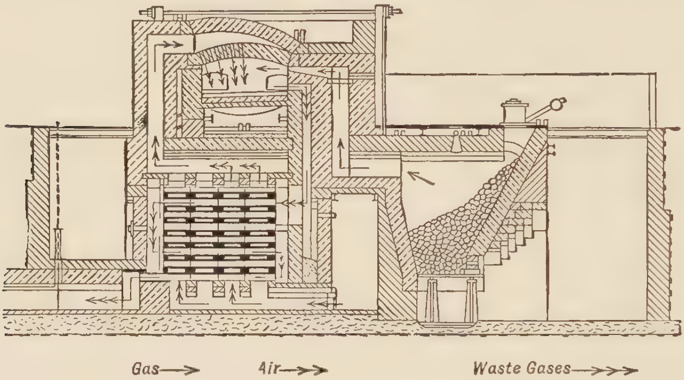

Fig. 83.—Semi-gas-fired furnace with self-contained producer.

of securing such coal make its use undesirable. For that reason some air is usually blown in above the fire by a blower. This portion of the air is commonly referred to as secondary air. If such air is not used the flame is very smoky with a thick fuel bed. It is likely to be very rash if all of the air is blown through a thin fuel bed.

The closed ash pit interferes with the cleaning of the fires. For that reason a clean-out door is occasionally provided immediately above the grate, as shown in Fig. 82. This door is made quite shallow, but is large enough for the operation of the slice bar.

One great trouble with coal-fired furnaces is the clinker which forms and sticks to the brickwork whenever the rate of combustion per square foot of grate per hour is high. In some cases (depend-

ing upon the rate of combustion and the composition of the ash) the clinkers build up from the four walls of the grate to such an extent that they must be chiseled off every Sunday. Clinker trouble is reduced by using carborundum bricks or by passing steam through the fuel bed. It is a well-known fact that steam breaks up clinker and keeps it from building up on the walls. Besides, if a mixture of air and steam is passed through a thick fuel bed, the latter is practically converted into a gas producer, and furnaces fired by this method are known as semi-gas-fired furnaces.

In practice, the conditions discussed in the foregoing paragraphs are dealt with in various ways. In many furnaces a steam jet induces air into the ash pit, while a fan blower furnishes dry secondary air beyond the bridge-wall. Figure 84 shows a grate and furnace of this type. A steam-jet type which does away with the closed ash pit was developed in Germany. It is shown in Fig. 85. In this type of furnace the grate lies in a trough through which air and steam are blown. The raking out of the ashes is thus made easier than in the closed ash-pit type. A similar design was patented in the United States in 1907, but it was not generally adopted.

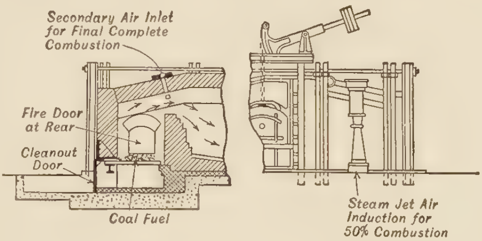

FIG. 84.—Coal-fired furnace with steam jet for forcing air into closed ash pit, and admission of secondary (dry) air.

Another method of supplying steam under the grate consists in having one blower furnish both primary and secondary dry air and in running exhaust steam from an engine or hammer into the ash pit. Still another method consists in raising steam in a water box above the level of the grate (see Figs. 86 and 87) and leading it below the grate. This arrangement keeps the clinkers away from the brickwork and can be used where neither exhaust steam nor live steam is available. On the other hand, it requires naturally soft water. If the water is hard, the box promptly fills up with scale.

This criticism applies particularly to the plain box (Fig. 86).

The water box of Fig. 87 is much better, for several reasons. The part which fills up with scale can be removed without dis-

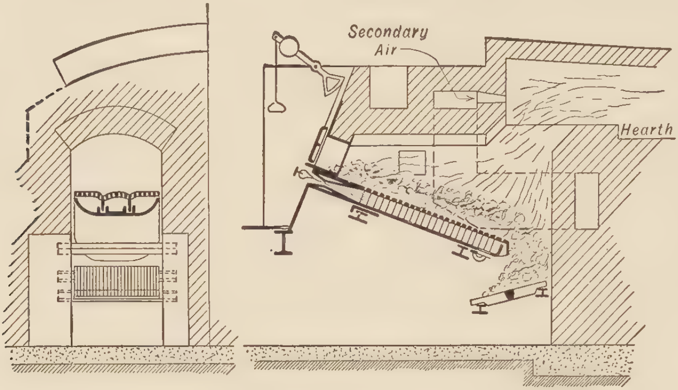

FIG. 85.—Coal-fired furnace with open ash pit.
Note that the steam jet forces air into hollow grate.

turbing the brickwork above the box. The part which is exposed to the fire can expand and contract independently. The top of the box, not directly in contact with the water, is protected against heat by a layer of bricks. The boxes in both illustrations should be made of soft, welded steel, to prevent cracking.

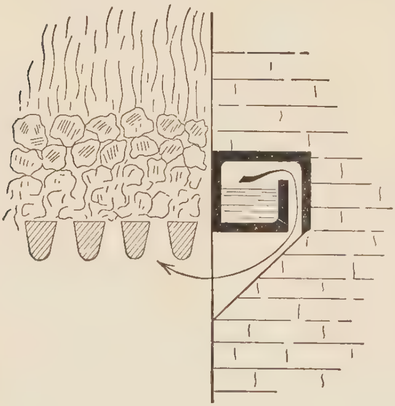

FIG. 86.—Water box for mixing steam with combustion air.

If steam is supplied regularly with the blast, below the grate surface, and if clinkering is further prevented by the use of carborundum bricks around the slag zone, as much as 50 pounds of coal may be burned per square foot of grate per hour. This high rate is used only in connection with melting furnaces. In annealing work and in the heating of sheets the rate of combustion is kept low enough to prevent clinkering.

In large coal-fired furnaces, in order to obtain fairly uniform

distribution of temperature throughout the furnace, it is often necessary to use several combustion chambers of moderate size, located at intervals along the furnace, rather than one very large combustion chamber. In such cases, if one large combustion chamber were used, with the low rate of firing, the condition of the fuel bed could not be kept uniform, and great temperature inequalities would result.

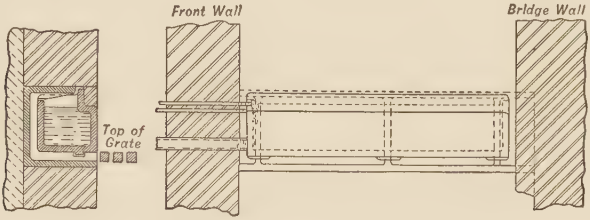

FIG. 87.—Sectional water box, removable for quick cleaning.

Mechanical Stokers for Industrial Furnaces.—The operation of any hand-fired grate depends upon the skill and the good will of the fireman. He may pick out lump coal, throwing the fines aside, shovel coal regularly, slice and stoke regularly, and keep the fire at the correct thickness; or else he may shovel large quantities at long intervals, allow ashes and clinker to build up, etc. In hand-fired furnaces there exists not only this possibility, but also that of an inrush of cold air when the fire door is open, although this can be avoided by a proper manipulation of the dampers. Finally, hand firing necessarily involves physical labor which is not very pleasant in front of a hot furnace. For all of these various reasons, stoker firing has become quite popular for coal-fired furnaces.

In spite of the deserved and growing popularity of mechanical stokers, one should guard against the belief that the mere installation of a stoker necessarily means an increase in fuel efficiency, and better furnace operation. When properly installed and correctly operated, stokers have that effect, without the slightest doubt. A few cases are known, however, in which stokers, which had been installed with the hope of good results, were later taken out because the results were inferior to those obtained with hand firing. In these cases the furnaces were so cramped that there was not enough room for the flame to develop in

the combustion chamber. Fortunately, such cases are the exception and not the rule. What the mechanical stoker does accomplish (provided that arrangements have been made for mechanical coal delivery to the hopper) is to abolish the physical labor of shoveling, and that feature in itself is enough to attract a somewhat higher class of labor. Unfortunately, however, some owners of stoker-fired furnaces have the mistaken idea that an unskilled heater can obtain good results with a stoker. Furthermore, not all types of stokers do away with the physical labor of ash removal and clinker pulling. Furnace-type stokers are now on the market with side dump plates, by means of which the clinkers can be dropped to the ash pit and then be easily removed.

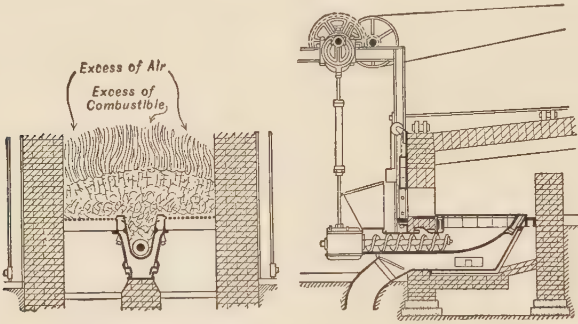

FIG. 88.—Underfeed stoker with screw feed.

From the reasoning given in the early part of this section it is clear that, for industrial furnaces, only those stokers which work with pressure under the fuel bed can be considered. It also follows that stokers should act as semi-gas producers, and such operation requires a deep fuel bed. Prevention of excessive smoke under this condition is obtained with underfeed stokers, two types of which are in common use on furnaces. They are shown in Figs. 88, 89, and 90. In either type the green coal is pushed in through a retort. In Fig. 88 feeding is accomplished by means of a screw, while a ram is the feeding device in the other stoker. Both stokers empty the mixture of coke, ash, and clinkers on to side grates; one of the stokers formerly emptied it on to dead plates, but side grates have been substituted.

In either case there usually exists a zone of heavy fuel from which combustible gases arise, and a zone of thin fuel from which excess

air rises, unless an unusually heavy fire is carried, in which case combustible gases rise without the entrance of excess air through the stoker. Secondary air is then supplied in the usual manner, for instance, through the bridgewall. For good combustion and for the sake of efficiency, secondary air must be dry. It should never be blown in by a steam jet. As corroboration of the statement that a stoker, unless it is equipped with automatic regulating devices, needs just as close attention as a hand-fired grate, the following reasoning is offered: If, in a stoker, the blast is turned on too strong in comparison to the fuel feed, the fuel bed will become thinner and thinner, the fire will become too hot, and a rash, oxidizing flame will result. If, on the other hand, the blast is turned down too low, the fire will gradually become thicker and colder. Any fuel bed is inherently unstable, by which is meant that thin, bright spots burn still thinner very rapidly. In hand firing, the fireman discerns thin, bright spots and covers them up. For this reason, constant supervision is a matter of course when hard firing is practiced. This necessity for automatic supervision does not exist in stoker firing; in consequence, the danger of letting

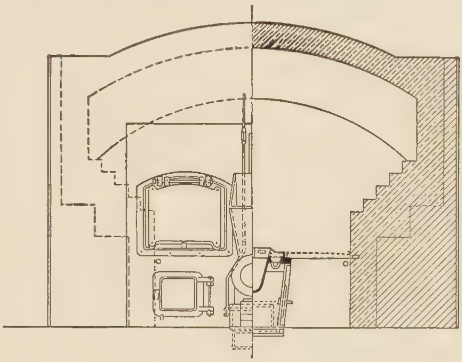

FIG. 89.—Underfeed stoker with feeding of coal by steam-operated ram. End view and section.

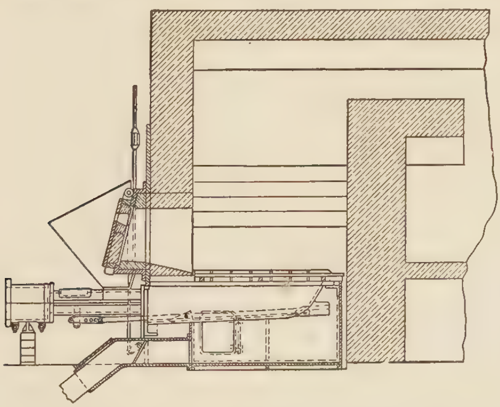

FIG. 90.—Underfeed stoker with feeding of coal by steam-operated ram. Longitudinal section.

the fire get out of adjustment is much greater when stokers are used. It follows that it is a penny-wise and pound-foolish policy to install a stoker, with the expectation that a less skilled heater will get just as good results with it as a more skilled heater would secure with hand firing. This statement is not an argument against the stoker, and is directed solely against the mistaken idea that all the heater has to do is to keep the hopper of the stoker full.

In the latest designs of the stoker shown in Figs. 89 and 90 the tendency to variation in the relation between the air supply and the coal supply has to a large extent been overcome by an arrangement consisting of an automatic valve, which maintains a constant relation between coal feed and air supply. By means of this arrangement the operator adjusts the rates of coal and air supply until he has found the correct relation. This being done, the nature of the products of combustion and the furnace temperature can be maintained within close limits, unless some other variable appears. The adjustment of the stoker, which must be checked from time to time, should not be left to unskilled labor.

Capacity of Grates and of Mechanical Stokers.—The grate area in coal-fired furnaces varies between the limits of 18 per cent and 30 per cent of the hearth area. The smaller area holds for lump gas coal. It might, at first thought, be imagined that high-temperature furnaces (2100° to 2300° F.) would require a large grate surface for a given hearth, and that low-temperature furnaces could get along with a smaller grate. This is not so. A low-temperature furnace (say, 1500° to 1600° F.) needs a grate working with a low temperature, and the latter is obtained only by a low rate of combustion. The temperature of the top of the fuel bed is determined as a balance between heat addition (due to combustion) and heat abstraction (due to the heat in the gases leaving the fuel bed and to radiation). From this fact it follows that (unless the combustion chamber is heat-tight) a high rate of combustion produces a hot fire, and a low rate of combustion results in a dull fire. But, since the latter is wanted in a heat-treating or in an annealing furnace, a slow rate of combustion must be used, which, of course, means a large grate.

Expressed in different terms, the required grate surface may be calculated from the quantity of fuel burned or gasified on it. Generally speaking, that area depends not only on the amount of coal, but also upon its quality, the size of the lumps, volatile

matter, quantity and composition of ash, upon the design of the grate, and upon the draft. For heating furnaces, additional considerations enter. Some of them were mentioned before and need not be repeated. There is, however, one additional consideration worth mentioning, namely, protection of the brickwork and of the stoker. While it is possible to burn 75 pounds of good gas coal per hour on one square foot of grate surface, with a draft of one inch of water, the temperature of the fuel bed resulting from so high a combustion rate burns out the roof over the grate and over the bridgewall within a few days. For that reason, 25 pounds per square foot per hour is seldom exceeded on heating furnaces for high-temperature work; while in annealing furnaces, 8 to 12 pounds per square foot per hour is

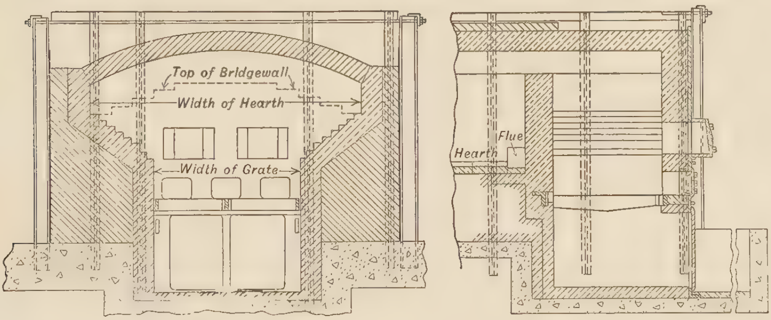

Fig. 91.—Grate with gradually widening combustion chamber.
Note the shape of top of bridgewall, intended to distribute the flow of gases uniformly.

an average value. It is, of course, quite possible to burn coal at a higher rate in annealing furnaces; but if this is done, the grate surface becomes much too small in comparison to the hearth area, and it becomes difficult, if not impossible, to secure uniformity of temperature all over the hearth. The truth of this statement will be realized from the steps which are found necessary for securing fairly uniform temperature with rates of combustion as low as 8 pounds per square foot per hour (see Fig. 91). In this illustration the width of the grate is less than that of the hearth. Uniformity of temperature is obtained by a gradual widening of the firebox in an upward direction, and by the shape of the top of the bridgewall.

The low rate of combustion which is used in connection with many hand-fired grates has an additional advantage. The

alternate streams or threads of combustible gases and excess air rise slowly and without turbulence in the combustion chamber, which, in this case, does not entirely deserve that name. When the gases pass into the heating chamber they are mixed, and a slow, sustained combustion is initiated, which heats all parts of the chamber uniformly.

Draft requirements are an important factor in determining the rate of combustion of coal on the grate. A simple relation between draft (loss of air pressure through the fuel bed) and rate of combustion would be welcomed by every furnace engineer; unfortunately, it cannot be found, because thickness of fuel bed, fineness and coking qualities of coal, and conditions of the fuel bed (ashes and clinkers) influence the result to a marked degree. For that reason, the well-known tabulations purporting to give the desired relation are only a crude approximation. Nevertheless, they give some information. For that reason, one of these tables is printed below (with the above-mentioned reservations).

TABLE XII

Draft Required above the Fuel Bed in Inches of Water

Kind of coal \ Rate	Pounds of dry coal burned per square foot of grate per hour						
	15	20	25	30	35	40	45
Eastern bituminous	0.12	0.16	0.20	0.27	0.34	0.42	0.52
Western bituminous	0.15	0.20	0.25	0.33	0.42	0.52	0.65
Semi-bituminous	0.15	0.20	0.28	0.37	0.48	0.60	0.80

From the values given for the draft, and from the equation given on page 258 of Volume I, the vertical distance between the grate and the hearth (if natural draft is used) can be computed. For instance, if 15 pounds of western bituminous coal are to be burned per square foot of grate area per hour, then the draft required above the fuel bed, from the table, is 0.15 inch of water.

Assume the temperature of the gases above the fuel bed to be 2000° F. Then

$$0.15=(0.192)(14.7)(144)\left[\frac{1}{(53.3)(522)}-\frac{1}{(53.3)(2460)}\right]\times H,$$

from which $H=12.6$ feet.

In very few furnaces can the vertical distance from grate to bridgewall be made as much as 13 feet. Therefore, with coal on the grate, there must be some negative pressure, or draft, in the furnace, unless the ash pit is put under pressure or the rate of combustion is lowered.

If primary air is to be blown under the grate by a steam jet the relations between draft, capacity of blower, and steam consumption can be taken from the catalogues of the manufacturers of steam-jet blowers.

In computing the rate of combustion on stokers it is customary to divide the coal burned or gasified per hour by the horizontal area of the firebox, which equals the area of the retort plus that of the side plates. If that method of calculation is followed, the rate lies between 6 pounds and 32 pounds per square foot per hour. The latter rate is a catalogue rate, which should not be carried out in practice because it results in a high maintenance cost due to burning out of tuyeres and to excessive formation of clinkers.

An idea of the relation between rate of combustion and air-pressure in the blast box can be formed from the following tabulation, which refers to the stoker shown in Figs. 89 and 90:

Rate of combustion, pounds of coal per square foot of area of retort plus side plates, per hour...........	5	10	15	20	25	30
Pressure in wind box, inches of water..	$\frac{1}{4}$	$\frac{3}{4}$	$1\frac{1}{4}$	$1\frac{3}{4}$	$2\frac{1}{4}$	$2\frac{3}{4}$

In view of the facts that coal must be delivered to every coal-fired furnace, that the ashes resulting from its operation must be handled, and that the removal of clinkers causes difficulties, advocates of gas or oil firing occasionally ask why hand-fired or stoker-fired furnaces still exist. The answer is that, in many localities, coal is very much cheaper than oil, city gas, or natural

gas (if the latter is obtainable at all), and that the installation of a gas producer, of a water-gas generator, or of pulverizing equipment, does not pay if only a single furnace or a small group of furnaces is to be served. Furthermore, it has been found that the fuel economy which is actually obtainable with gas-fired or oil-fired furnaces is, in many cases, much lower than might be expected from the theoretical possibilities of such firing, because misadjustment and oversupply of fuel do not involve any exertion on the part of the heater. In coal-fired furnaces, and particularly with hand firing, careless operation results in increased physical labor of shoveling and coal passing, and in the removal of increased quantities of ashes and clinkers. The heater thus has a selfish interest in economical operation.

For all of these reasons, coal-fired furnaces will continue to be used and installed, and their installation in the proper places will be good engineering. One possible danger in their installation is the tendency to add more and more coal-fired furnaces to a growing plant, even after the latter has grown to a size which would well justify the installation of gas-making or coal-pulverizing equipment. This fact, however, is no argument against the use of coal on the grate in its proper place.

COMBUSTION DEVICES FOR POWDERED COAL

Properties of Powdered Coal.—Some of the advantages which gas and oil have over coal on the grate are also offered by the use of coal dust. Briefly stated, these advantages are: inexpensive transportation of fuel to furnaces; uniformity of temperature over hearths of considerable size; a small amount of excess air (which means smaller furnace losses by oxidation); better control of rate of combustion; and quick heating from a cold start.

The use of powdered coal involves two separate sets of equipment: one is the grinding and distributing equipment, while the other consists of the devices for feeding and for mixing the coal dust and the air. While the equipment which serves for pulverizing and distributing is extremely important for the successful use of powdered coal, a description of it does not belong in a treatise on industrial furnaces, and will not be given here. Nevertheless, the result of the pulverizing equipment, namely, the condition of the coal dust with regard to fineness and dryness, affects the combus-

tion as well as the deposits of ash. For that reason, these features of the grinding plant must be mentioned as far as their effect upon combustion is concerned.

By far the greatest part of our supply of coal dust (the word is used here in the sense of " pulverized coal ") is made from bituminous coal, that is to say, from coal which contains a large amount of volatile matter. In the combustion of the dust, four phases occur, namely, (1) heating and drying of the dust, (2) gasification of the volatile matter and coking of the carbon, (3) combustion of gases, and (4) combustion of the coke dust. In practice, these phases overlap to some extent. A mathematical investigation of the combustion of powdered coal is impossible in the present state of mathematics and physics; for that reason, the following, more or less rambling, general reasoning is offered.

Heating of the dust, degasification, and ignition of the gases require a hot combustion chamber or, more correctly speaking, ignition chamber. With some of the burners, lighted oily waste, held in the path of the coal dust and air mixture for four to six minutes furnishes sufficient heat for ignition, particularly if the coal dust is made from a high-volatile coal. In many other cases, a wood, gas, or oil fire is needed for starting; while, in regular operation, the combustion of the liberated gases maintains the high temperature which is needed for quick ignition. While ignition and combustion of the volatile matter take place quickly, on account of the diffusion of the gases, the ignition and combustion of the coke particles are comparatively slow.

As soon as the mixture of air and coal particles enters a hot combustion space, it receives heat by radiation, and this heat is absorbed quickly by the solid particles. The latter, in turn, heat the surrounding air by convection. The less air is mixed with the coal dust, the less heat is abstracted from the heated coal particles, and the more quickly ignition is initiated. Obviously, if quick ignition is desired, it is advisable to mix only a fraction of the combustion air with the coal dust before injection and to add the rest of the air in the furnace after ignition has occurred. Tests have shown that the fraction of the combustion air which should be mixed with the coal dust before injection is about 40 per cent. (Engineers Society of Western Pennsylvania, 1923, page 247.) Evaporation of residual moisture, and liberation of the gases, absorb an additional amount of heat, before the tem-

perature of the particle can be raised to the ignition point. In view of these facts, it seems paradoxical that ignition of coal dust made from high-volatile coal is easier than that of dust made from coke or anthracite, particularly if it is remembered that the ignition temperature of coal lies far below that of the liberated gases.

The explanation lies in the circumstance that the burning stream is ignited not only by radiation from the hot furnace walls, but also by radiation and conduction extending backward from the flame. It is in the latter method of ignition that the greater mobility of gaseous matter accelerates the process of combustion. In this connection, it is of interest to note that, while extremely fine grinding delays ignition by radiation from the combustion chamber, it increases the velocity of flame propagation and thereby helps ignition. These relations were mathematically investigated by Dr. Nusselt and were published in the *Zeitschrift der Vereines Deutscher Ingenieure* of February 9, 1924.

Carbon burns just as rapidly as it can find oxygen. During combustion, each coke dust particle surrounds itself with an atmosphere of nitrogen and carbon dioxide, through which oxygen can penetrate only by diffusion or by turbulence. One volume of coke needs approximately 14,000 volumes of air under atmospheric conditions; in consequence, each particle of coke needs an air volume of 24 times its own diameter. For furnace conditions, the ratio of diameters grows to about 35. Within this sphere, or cube, the outer layers of oxygen must find their way to the core, where the dust particle floats. Evidently, this fact is accomplished much more easily if the air sphere is small, that is to say, if the coke particle is of almost molecular dimensions. However, this condition is very far from being realized in practice. If a large portion of coal dust passes through a 300-mesh sieve, the average grain of that dust may be assumed to have a diameter of $\frac{1}{500}$ inch. The surrounding air sphere then has a diameter of $\frac{35}{500}$ inch, or approximately $\frac{1}{15}$ inch. This dimension is more than a million times larger than the diameter of a molecule of air. In consequence, the combustion of coal and coke dust follows the laws of the combustion of solids, and not of gases, in spite of the outward similarity of a gas flame and a coal-dust flame. For coke particles burning with much excess air, Nusselt has computed the time which is required for combustion, if oxygen reaches the

carbon by diffusion only. He finds the values given in the following table:

TABLE XIII

Diameter of carbon particle, inches........	0.08	0.04	0.008	0.004	0.0016	0.0008	0.0004	0.00008
Time required for combustion, seconds..	400,000	100,000	4000	720	198	40	10	0.36

If the excess air is reduced, the time required for combustion increases, as determined by Nusselt's theory, in this manner:

TABLE XIV

Ratio of actual air to theoretical air....................	1.0	1.1	1.2	1.3	1.5	2.0
Ratio of actual combustion time to minimum combustion time.................	Infinity	3.58	2.67	2.26	1.86	1.49

These values are based upon air motion by diffusion only, and neglect air motion by turbulence, which will be mentioned later on under "Burners." In reality, combustion takes much less time than the values of the table would indicate. Tests on the time actually required for the combustion of powdered coal were made by Director Audibert of the French Bureau of Coal Mines. He found that, with average coal, and with coal particles having a diameter of 0.0026 inch, from 0.18 to 0.55 second was required for complete combustion. For particles having a diameter of 0.007 inch, the time required for complete combustion, with the theoretical quantity of air, ranged between 0.58 and 0.90 second. The time required for combustion depends not only upon the size of the particles, but also on the size of the nozzle through which the coal dust is blown into the furnace, and upon the kind of coal. A coal with about 25 per cent volatile matter appeared to burn

faster than any other. Since coal dust is very seldom blown into the combustion space with a velocity of less than 30 feet per second, it follows that, for the particle given above, the diameter of which is 0.0026 inch, a flame length of 0.18 times 30, or about $5\frac{1}{2}$ feet, is the minimum which can be attained. The coarser particles require a considerably greater length of path for complete combustion. If the dust is blown into the furnace with excessive velocity (values for which will be given later) through a round opening, the path must be long.

In this respect, coal dust differs essentially from gas or oil mist firing. The higher the velocity of a gas jet, the greater is the speed of combustion, because of induction, entrainment, and turbulence; but the same is not true in the same measure for coal dust. With the latter, the length of time required for combustion remains approximately the same regardless of the velocity of injection, so that high velocities result in long flame paths. The solid nature of the coke particles has the additional effect that the length of path required for combustion does not depend upon the diameter of the coal-and-air jet to the same extent as it does in gas or oil flames. In the latter, a jet of small diameter results in a short flame. The length of path required for complete combustion and the flame temperatures obtained with cold air under average conditions are illustrated in Fig. 92. The data were obtained by the A. E. G. of Berlin, Germany.

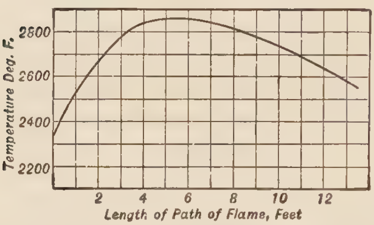

FIG. 92.—Relation between flame temperature of powdered coal and the smallest length of path for unrestricted flame development.

It also follows that, within the limits of suspension of the dust, the length of the flame path is a function of the coarseness of grinding. If the dust is too coarse, it drops out of the path of the gases. Fine grinding, however, although it reduces the length of the flame, is expensive inasmuch as it requires either a high-grade grinding outfit, and as much as 25 per cent more power than coarse grinding, or else, with an inefficient grinding machine, very much more power than is required for coarse grinding. We thus find two conflicting elements: inexpensive (coarse) grinding

necessitates the use of long and expensive combustion chambers; while the use of small and inexpensive combustion chambers necessitates expensive (fine) grinding. It is impossible to determine, by theory, the best compromise between these two extremes. Besides, the content of volatile matter in the coal makes a difference, because, as before stated, the suspended coal particles are more rapidly ignited by the burning gaseous matter of highly bituminous coal. Experimentation and practical (oftentimes bitter) experience have led to the conclusion that the residue on a 200-mesh sieve should not exceed 10 per cent to 20 per cent, even for large furnaces, such as cement kilns, open-hearth furnaces, and the like.[8] The smaller the furnace, the finer should be the grinding; otherwise the furnace must be made large solely for the purpose of providing sufficient combustion space. This fact brings out the difficulties which have existed in adapting powdered coal to small industrial furnaces, and proves the desirability of devising methods by which uniformly fine grinding can be obtained with a reasonable expenditure of power and with a reasonably low investment cost.

It must be understood that most of the harm done to the brickwork of furnaces that are fired with powdered coal is due to the coarse particles (called " nibs " in British cement practice) which are not burned in suspension, but either strike the walls or else pass out partly burned. If they strike the wall, the ash may form a corrosive slag which destroys the furnace brickwork. If they pass out under and around the furnace doors, the coke and ash particles lodge on the equipment of the furnace room, unless they are carried off by a hood. Furnaces with hoods serving this purpose were described in the *Iron Age* of February 21, 1924.

The action of powdered coal upon brickwork varies greatly with the composition of the ash, and with the furnace temperature. High furnace temperature and easily fusible ash produce slag, while low furnace temperature and ash of a high fusion point produce solid ash dust. In a boundary case between these two extreme conditions a very viscous slag (similar to molasses in stiffness) is produced. This slag congeals whenever the doors are opened, and its removal causes much trouble, unless the furnace temperature can periodically be increased to the point at which

[8] For large boilers, a residue of 30 per cent is allowed on a 200-mesh sieve.

the slag becomes thin enough to be tapped off. It is quite evident, from these explanations, that many variables enter into the combustion of powdered coal, and that as simple a change as the substitution of one kind of coal for an apparently similar one, may upset smooth working conditions and cause trouble and vexation until the method of operation has been adapted to the new coal. This statement should not be construed to mean that only a few coals are suitable for being burned in powdered form. On the contrary, the range of coals is very wide, a greater variety of them being suitable for this purpose than for any one type of stoker. It means, however, that the practice followed in slag removal, and time between furnace repairs will vary with the nature of the coal.

Another property of powdered coal which must be considered in the design and operation of combustion devices is its affinity for moisture; powdered coal is hygroscopic to a degree which varies very largely with the composition of the coal. Certain salts contained in the coal are very hygroscopic, while others are less so. In consequence, one kind of coal (lignite or brown coal), when dried in a current of air of 105° to 110° F. temperature, will contain more moisture than other coals (semi-bituminous) dried under the same conditions. Again, certain coals can be stored for a long time without absorbing noticeable quantities of moisture.

In general, very dry coal dust flows almost like water. If it absorbs moisture, it behaves like wet table salt.

The use of reasonably dry dust is advisable, because damp powder (particularly with certain kinds of coal) tends to stick to the walls of the hoppers, ducts, and feeders, and to form arches, thereby interfering with regular feeding. If fed immediately after grinding (without being stored) most coals do not require drying, because the powder has had no time to absorb moisture from the atmosphere. Besides, it has not had time to become compacted.

In this connection caution is necessary. Most coals pulverize well and feed well with but little drying. The manufacturer of grinding and feeding equipment may attribute the good results obtained with a given coal to the merits of his apparatus, instead of attributing them to the nature of the coal, with the result that the same apparatus, when used with another coal, may be a

failure. The following figures are, for that reason, averages only. Anthracite is dried to $\frac{1}{2}$ to 3 per cent moisture; bituminous coal is ground with moisture between $\frac{1}{2}$ and 4 per cent; while brown coal and lignite are ground in the range of 5 to 20 per cent moisture. Origin of fuel, type of grinding mill, and use of fuel are responsible for the range given with each fuel.

In connection herewith, it may be mentioned that there apparently exists a point beyond which drying cannot be carried economically. The major portion of the moisture content of fuel seems to be surface moisture, while the remainder is "inherent," or "chemically combined," moisture. The former is driven off easily; the latter, with difficulty. When solid fuels are dried beyond the point at which their hygroscopic moisture is in equilibrium with the atmospheric moisture, they tend to absorb moisture if left exposed to the atmosphere. This fact may be observed particularly well in connection with lignite.

For the design of feeders, it is of importance to know that the specific gravity of newly ground coal dust ranges between 0.56 and 0.72, while the specific gravity of coal is about 1.2. The difference is, of course, due to the air spaces between the coal particles. If coal dust is densified or compacted by shaking, its specific gravity can be increased to about 0.8 or 0.9.

Feeding Devices or "Feeders" for Powdered Coal.—Combustion devices perform the function of feeding the powdered coal into the furnace in a regular manner, which is subject to reliable regulation with regard to quantity; and also that of mixing it with air in such a manner that combustion will take place as desired. The service which the combustion device should be capable of rendering has been aptly defined by the words "flame control." With powdered coal, feeding the dust to the furnace and mixing it with air are, in many devices, separate functions. For that reason it will be advisable to discuss them separately, with the understanding that, in some of the devices, the two functions cannot be kept apart.

Although it has been said that coal dust flows almost like water, the feeding of coal from a bin at a constant rate is by no means a simple matter. The rate at which powdered coal will flow through an orifice, even if the head is kept constant, varies with the dryness of the material, its state of aeration, and its fineness. All of these features vary from time to time, on

account of the more or less irregular motion of the coal through the bin. Powdered coal fed through an orifice travels in waves, or "gulps." It must, therefore, be fed by other means, which may take the form of mechanical transportation, or of the frictional drag of gases moving at high velocities.

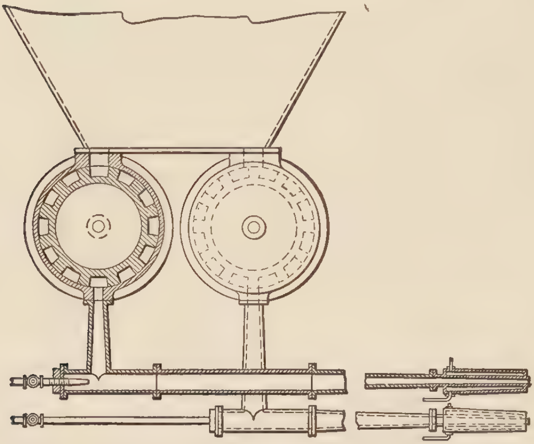

Fig. 93.—Early type of drum feeder for powdered coal.

In the utilization of either method, the principle is to drop the coal dust from the hopper into the feeding device by gravity and to vary the speed or the drag of the feeding device proper, within the limits required by the furnace. The design must be such that shutting down the feeder stops the flow of coal.

The great majority of mechanical feeders are either of the drum or of the worm type. Other types are used locally, but have not been generally adopted. Drum types are shown in Figs. 93, 94, and 95. In these, cavities at the circumference of the drum transport

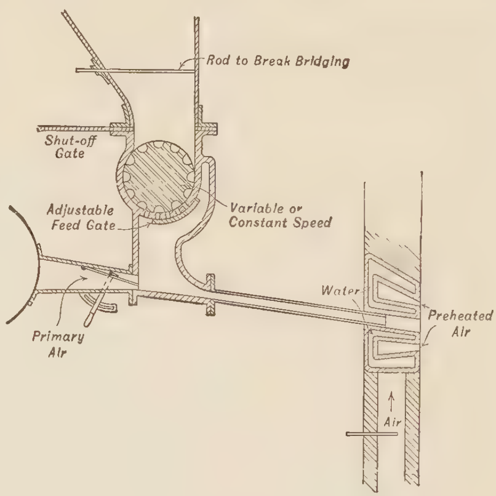

Fig. 94.—Drum-type feeder for powdered coal. Note provision for use of preheated secondary air.

coal dust from the hopper to the pipe supplying the burner. Variation of feed is obtained either by variation of speed of drum, or by adjustment of admission of dust to drum (variation of face or axial length to which coal is admitted) by a sliding gate, or finally by partial discharge (carrying part of the coal back and around). The early drum feeders, such as the one illustrated in Fig. 93, work satisfactorily with well-dried and finely ground coal, if the drum is rotated quite slowly. Wet coal dust, working into the ends of the drum, causes a great deal of trouble. The feeder shown in Fig. 94 was developed about 1919 and is still in operation. It is not regularly marketed. The feeder shown in Fig. 95 is of recent design.

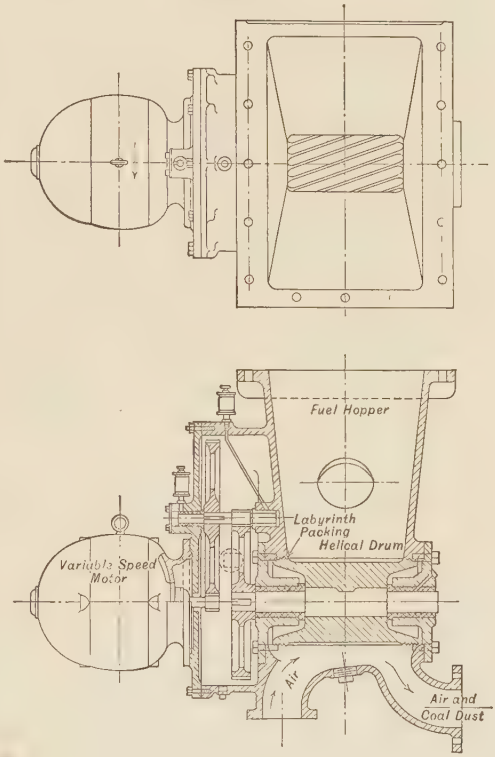

FIG. 95.—Drum feeder with helical grooves.

Note labyrinth packing for preventing dust leakage; direction of air blast for cleaning powder out of grooves; and variable-speed motor for regulating rate of feed.

In this feeder the drum with helical grooves, operated by a variable-speed motor, feeds coal at a uniform rate from the upper hopper. The air passage below the gear is designed to cause the air stream to impinge on the bottom of the gear and to blow the coal dust out of the grooves. To prevent the coal dust from escaping into the spaces at the ends of the drum, labyrinth packings are provided. If any coal should enter these spaces it would drop into the air stream and would be removed by it. In any case, as the air is under a slight pressure, the tendency would be

for a little air to leak into the bin, rather than for the coal dust to leak into the air space, except when the feeder is not working.

On account of the troubles mentioned above as having been caused by the older designs of drum feeders, most experimenters turned to worms (feed screws), which have been highly developed and have found widespread application. There are many screw feeders on the market, and one example will explain the type (another example will be illustrated later on under "Burners"). Figure 96, which illustrates a feeder and air mixer developed in the early stages of powdered coal firing, shows the characteristic features. The feed screw lies under a wide opening of the hopper, and by its continued motion breaks up any tendency of the coal

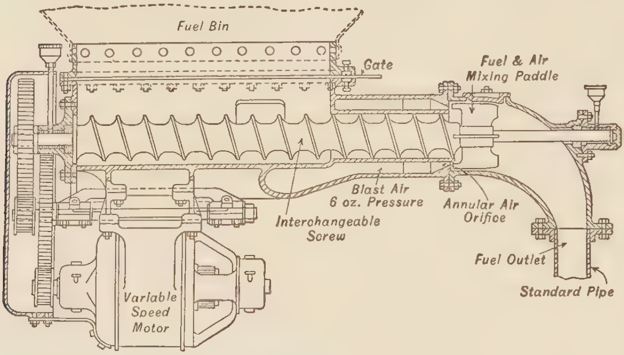

FIG. 96.—Screw-feed mixer for powdered coal.

Note air admission and mixing paddle at end of screw and variable-speed driving motor.

to arch over. In some designs, this precaution has been thought to be insufficient, and an agitator provided with prongs is revolved above the screw or screws, to aid in preventing the coal from arching over. It will be noticed that the screw extends beyond the admission opening, a distance in excess of the one which corresponds to the angle of repose of the finest coal dust in the screw pipe. Feed screws, acting without the aid of the other devices, were found to deliver coal dust in puffs at low rates of delivery. The trouble was overcome by mixing some air with the coal at the end of the screw and by providing a paddle for stirring the mixture. Air with 6 ounces (10 inches of water) pressure passes through an annular orifice, around the screw, producing a coal-and-air emulsion of about one-to-one by weight.

If the screw feeder is intended for a powdered-coal furnace with a wide range of heating capacity, the speed of the feed screw must be adjustable within wide limits. On large furnaces, two or three feeders can be provided, some of which can be stopped at light loads.

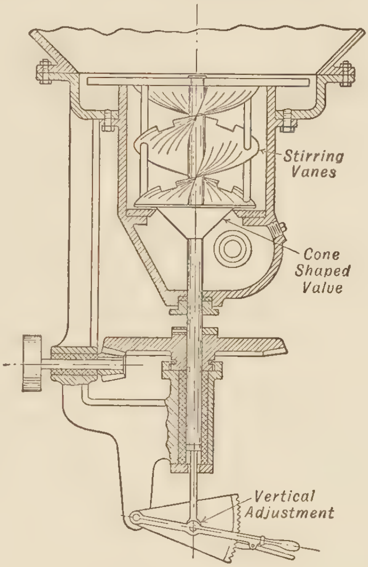

FIG. 97.—Vertical feeder with stirring vanes and cone-shaped regulating valve.

A very simple feeder is shown in Fig. 97. By means of belt and bevel gear drive a vertical shaft rotates a cone-shaped valve and also stirring vanes above the valve. The rotating valve can be raised or lowered by hand adjustment. A current of air, passing under the valve, removes the coal dust and carries it to the furnace.

In the so-called "siphon" feeder, the principle of which is illustrated by the sketch, Fig. 98, an attempt has been made to avoid the expense connected with mechanical feeding and its close dependence on the power plant. Under the action of gravity, coal dust settles in the horizontal pipe as indicated by the dotted line, the inclination of which varies with the condition of the coal. As soon as compressed air is turned into the central pipe, coal is carried along by the combined action of the vacuum and of the frictional drag which the jet produces. The greater the amount of compressed air which is supplied, the greater the amount of coal which is carried along.

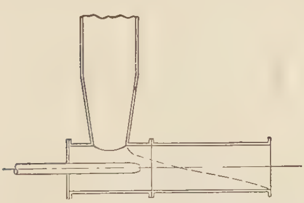

FIG. 98.—Diagrammatic sketch of siphon feeder for powdered coal.

Another method of feeding consists in equipping each furnace with an individual pulverizing mill, including a fan. Regulation of the mill controls the supply of coal dust to the burner. In this

case the feeding is accomplished by air, which carries coal dust in suspension. At present this method is applicable to large furnaces only, because small pulverizers have not been developed to the point where they can furnish uniformly fine coal dust at a reasonable investment, a reasonable expenditure of power, and a reasonable cost of maintenance. Another difficulty which has not been overcome with unit pulverizers is uniformity of pulverization with regard to time. Many grinders work well when new, but after some time deliver large particles of coal.

In air feeding systems, coal dust is carried around in a ring piping system; the dust is suspended in air, which amounts to one-fourth to one-half of the air required for complete combustion. The air in the coal-and-air main is under a slight pressure. A gate valve or other straight-way valve controls the flow of air from the main to a furnace, and also controls the flow of coal dust.

Regulation of feed in the circulating system depends upon several circumstances, among which are (1) regularity of composition and of pressure of circulating coal and air mixture, and (2) size of the circulating pipe, which must be small enough to prevent segregation of the coarse particles at light loading of the system.

Burners for Powdered Coal.—The purpose of burners is to mix coal dust and air in correct proportions and to inject the mixture into the combustion chamber in such a manner that complete combustion occurs in the furnace, without injury to either the furnace or the material which is being heated. In practically all systems of combustion of powdered coal, the entering coal dust is already mixed with a certain amount of air (which is sometimes called "primary air") in the feed pipe. The rest of the combustion air (termed "secondary air") is admitted to the combustion chamber through separate openings, which lead either directly into the combustion chamber or else into the burner.

The secondary air varies within the limits of 30 to 85 per cent of the total combustion air, depending upon conditions. If any of the air is to be preheated, it must be the secondary air. The primary air must be cold, if sticking and coking of the dust in the burner is to be avoided.

Burners are often classified in accordance with the pressure of the primary air. Low-pressure burners work with an air pressure of 1 to 12 inches of water, while high-pressure burners work with

a pressure of 35 to 100 pounds per square inch. From statements made earlier in this chapter, it follows that high-pressure burners working with a high percentage of primary air (or " emulsion air ") produce long, narrow flames, while low-pressure burners work with shorter ball-shaped flames.

If powdered coal is mixed with a large percentage of the theoretical combustion air, and if the mixture is blown into the combustion chamber at high velocity, a long flame results, for two reasons: as previously stated, the coal particles are brought up to ignition temperature quite slowly, if the heat which they receive by radiation is given up by convection to a large weight of enveloping air. This circumstance delays ignition if the percentage of primary or emulsion air is high. Second, coal particles require a long time for combustion, if air can reach the coal particle only by diffusing through the layer of products of combustion which surrounds each coal particle and which, in the assumed case, travels with it.

If coal-air emulsion with a small percentage of combustion air (15 to 30 per cent) is blown into the combustion chamber at reasonably high velocity, and if the rest of the air is blown into the path of the coal, combustion is quickened, and the flame is shortened. This is particularly true if the jets are of small diameter, and if the coal powder is uniformly fine. The coal particles which are heated by radiation are not cooled by so much air and are, for that reason, ignited more quickly. Secondly, they are driven through stagnant or almost stagnant air, by which action the shell of products of combustion surrounding each particle is continuously scrubbed off and is replaced by air. Reasoning of this sort would appear to indicate the futility of attempts to mix the powdered coal with all of the combustion air before it enters the furnace, particularly if high pressures and velocities are used.

It follows that, in addition to being simple and easily attached, burners should produce intimate mixing of coal dust and primary air in the delivery pipe, and quick, thorough mixing of coal-air emulsion and of secondary air in the combustion chamber. They should allow variation of coal quantity fed and mixed in unit time, and should also allow adjustment of the fuel-to-air ratio. In industrial furnaces, adjustment of the direction of the flame is desirable. Any features which promote quick ignition are ad-

vantageous, except in certain annealing furnaces, in which a lazy flame is desired.

It will pay to study various types of mixers and burners with a view to finding out how close they come to embodying the above theoretical reasoning. In view of the complicated phenomena which surround the combustion of powdered coal, one might expect the burners to be scientifically designed for the purpose of effecting ignition and combustion in the quickest possible manner; but as a matter of fact, most " burners " are very simple affairs, consisting of nothing but a pipe, which blows the coal-air mixture into the combustion chamber and induces secondary air through a hole which surrounds the pipe. Occasionally, the coal-air feed pipe is located in a tall combustion chamber similar to the one shown in Fig. 82. In this case induction of secondary air is not necessary, because the draft in the combustion chamber draws in air, although a slight pressure may exist over the elevated hearth of the heating chamber. While some burners are very simple, a few are quite complicated. In practice, however, results are not necessarily proportional to complication, and it appears that no generally accepted method exists for the combustion of powdered coal. One man, particularly well posted on matters of combustion, sums up the burner situation in these words: " The combustion of powdered coal is to-day guided more by Christian Science than by theory."

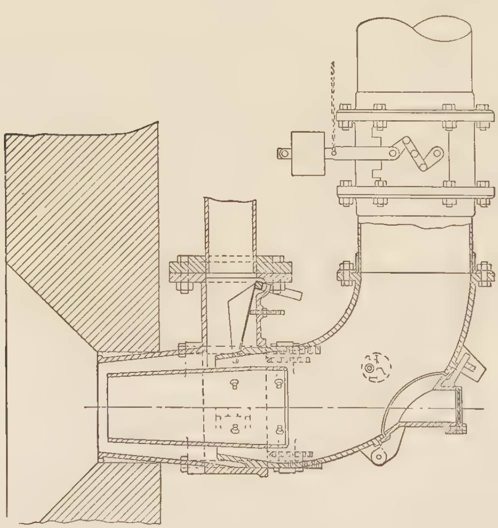

Fig. 99.—Burner for powdered coal with core of secondary air admitted inside a ring of coal-air emulsion.

In addition to the foregoing classification of burners with regard to air pressure employed, they may be further classified with regard to the ratio of primary air to total combustion air.

Consider first those burners which use a small percentage of primary air. In that type a further subdivision can be made according to the method of admitting secondary air. The latter can be admitted as a core inside of a ring of coal-air emulsion, or else as a ring which surrounds the core of coal-air mixture. An example of the former type is shown in Fig. 99. It is claimed that the core of secondary air expands and penetrates through the coal-air emulsion, furnishing air for combustion as it is needed. Examples of the latter type are shown in Fig. 100 and in Fig. 101. Both of these designs are based on the theory of forcing the outer current of air into the central coal-air mixture. The supply of secondary air is adjustable in either burner, a lever serving in one case, while a handwheel with a rack and pinion serves in the other case. The secondary air sweeps over the edges of the burner,

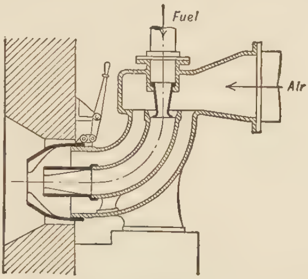

Fig. 100.—Burner for powdered coal, in which an outer ring of secondary air is made to impinge upon the core of coal-air emulsion.

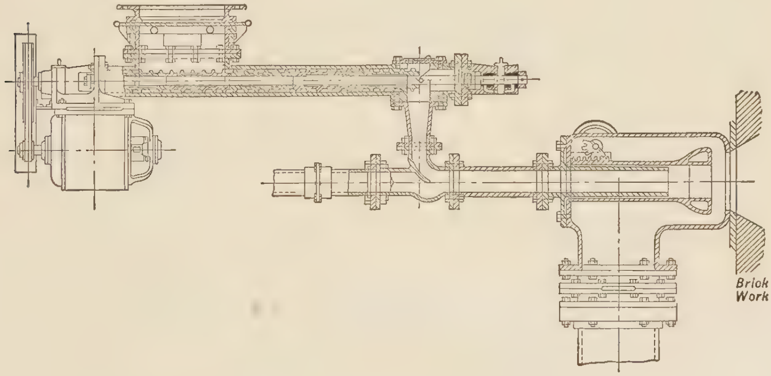

Fig. 101.—Screw feeder and mixer in which secondary air is forced from the outside into the core of coal-air emulsion.

which are exposed to the furnace heat, it being claimed that this action cools the edges. While both of these burners (Figs. 100 and 101) form compact, self-contained units, there may be some argument about the point at which the secondary air is admitted. Ignition and combustion would probably be quicker if the second-

ary air were admitted through annular slots surrounding the primary mixture, in two or three stages, as indicated in Fig. 102. No burner embodying this feature is on the market at the time of writing this chapter. It may be remarked that the burner shown in Fig. 94 mixes in the furnace.

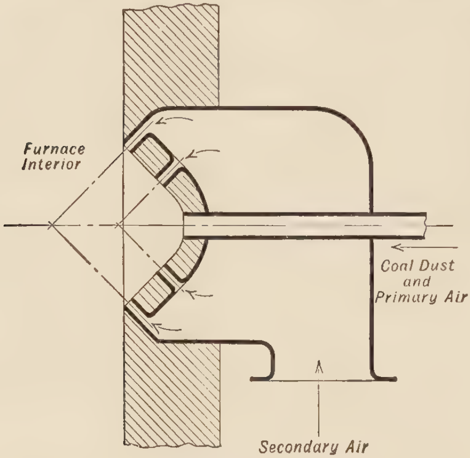

FIG. 102.—Diagram of burner with admission of secondary air in several stages.

Note parabolic shape of burner body, for concentrating heat reflected from the furnace on the stream of coal-air mixture, in order to quicken ignition.

A high-pressure burner (served by a siphon feeder) is shown in Fig. 103. This type of burner is adapted (because of the length of its flame) to use in cement kilns, open-hearth furnaces, or large-size regenerative heating furnaces.

Figure 104 represents a burner in which the powdered coal and all of the combustion air are thoroughly premixed before they

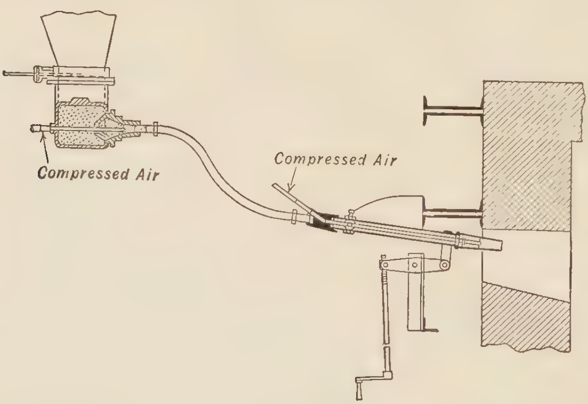

FIG. 103.—High-pressure burner with siphon feeder, producing long flame.

enter the combustion space. It is somewhat doubtful whether this burner will fulfill the hopes which its inventors had for it. Theo-

retical reasoning, as well as practical experience, seems to indicate that, in the combustion of powdered coal, thorough premixing with all of the air produces slower combustion than turbulent mixing with secondary air in the combustion chamber, or at the mouth of the combustion chamber.

On the other hand, the idea that, for best results, there must be thorough premixing of coal and all of the combustion air in the feed pipe is steadfastly maintained by some engineers. Figure 105 shows a combination feeder and burner, in which thorough mixing

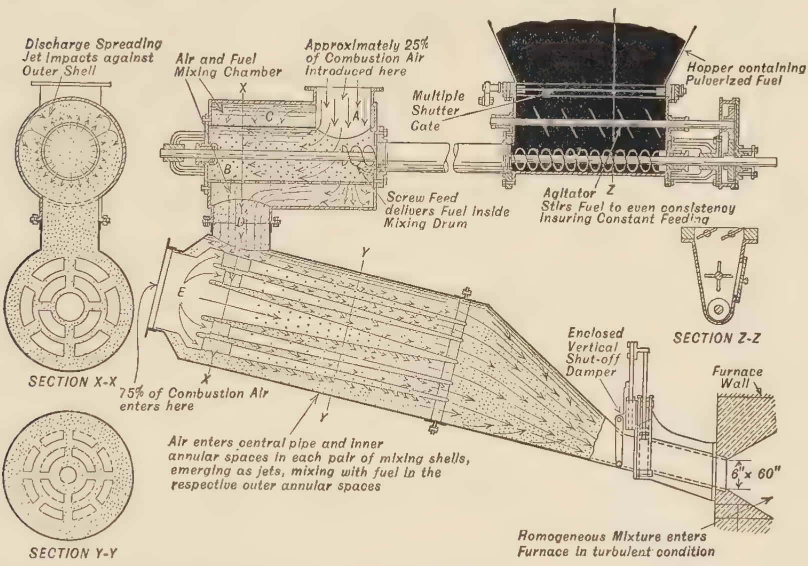

FIG. 104.—Burner designed for thorough premixing of coal with total quantity of combustion air.

is obtained by having the coal and air mixture impinge upon a stationary, fan-like member in a "carburetor."

On account of the complexity of the phenomena surrounding the combustion of powdered coal, standardization of the combustion equipment will probably not be achieved for many years, and the relative merits of partial and total premixing will doubtless continue to be a matter of argument. On the other hand, it must be understood that a practical limit is set to the speed of combustion by the strength of the combustion chamber. Practically instantaneous combustion would result in so high a

flame temperature that any (but a water-cooled) combustion chamber would be melted down.

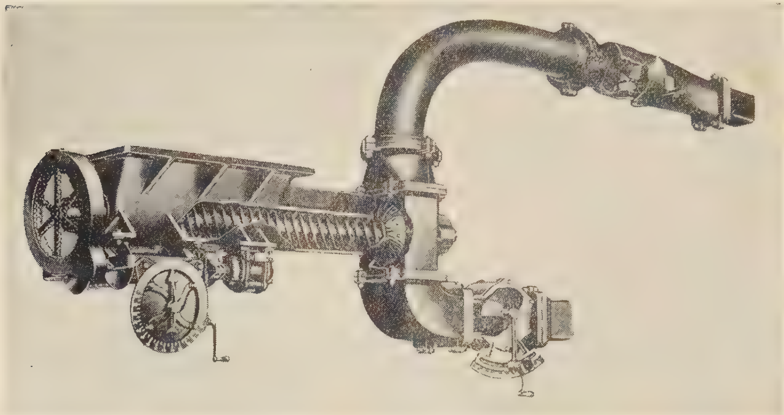

FIG. 105.—Screw feeder and burner, with carburetor designed for complete premixing with all of combustion air.

As interesting examples of historical development, drawings of two older types of burners, which, however, are found to-day

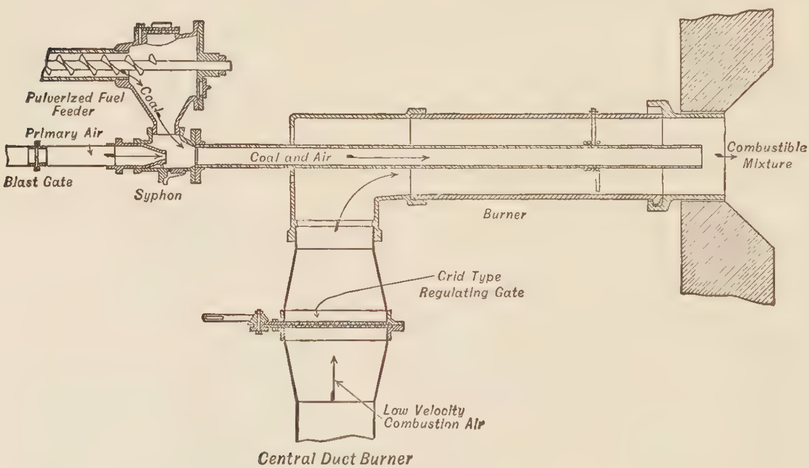

FIG. 106.—Screw feeder and mixer in which a central core of coal-air emulsion is surrounded by a parallel stream of secondary air.

with but slight modifications, are here reproduced. Figure 106 shows a very simple arrangement in which a central coal-air emul-

sion is surrounded by a ring of air. By proper proportioning, this burner can be made to work very well. Figure 107 shows a burner in which the combustible mixture travels a certain distance before it enters the furnace, for the purpose of producing a thorough mixing. In this case, the velocity must be sufficiently high to prevent back flares, which means that the burner cannot be used over a wide range.

Capacity of Burners for Powdered Coal.—The velocity of flame propagation of a mixture of coal dust and air probably lies between 8 and 14 feet per second. At the lowest rate of fuel

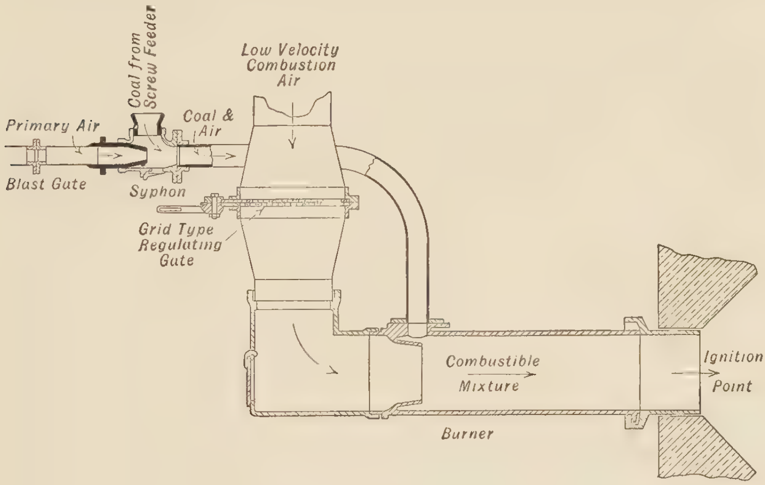

FIG. 107.—Burner with passage for producing thorough mixture of emulsion with secondary air.

delivery the velocity must exceed these values. At the normal rate of fuel delivery, the velocity in the burner must be 3 to 4 times that of the velocity of flame propagation. In consequence, low-pressure burners are designed for velocities of secondary air ranging from 30 to 60 feet per second; the velocity of the emulsion of coal and primary air should be somewhat higher, reaching 100 feet per second. As before mentioned, a certain velocity difference between the two streams of air is desirable in order to stimulate mixing. Regulation of the heat developed does not take place in the burner, but in the feeders, which were described before. On the other hand, it is very desirable that the amount

of air delivered be regulated at the burner. No fixed system exists for regulating the amounts of primary air and of secondary air. At some burners the primary air remains practically constant, regardless of the amount of coal coming in. In that case, the secondary air should, by rights, be adjusted to suit the quantity of coal delivered. If the secondary air is delivered by a blower, regulation is accomplished by the adjusting of a slide gate. If the secondary air is drawn in by induction, the supply is regulated by varying the size of the opening through which the induction air passes into the combustion chamber. Devices for automatically proportioning the quantity of coal delivered and the quantity of air supplied are not on the market at the present time. As a rule, the correctness of the air supply is judged by the eye of the heater or fireman.

Combustion Chambers for Powdered Coal.—At first thought it may not appear proper to consider the combustion chamber as a part of the burner or of the combustion device, but, with coal dust, the combustion chamber is indeed an important part of the whole combustion equipment. As previously mentioned, unburned particles of coke and ash must be kept away from the highly heated firebricks, because a corrosive slag is formed by some kinds of ash, and tends to eat away the brick walls. It may be stated, however, that, with some coals and some burners, ash has impinged upon walls without causing serious trouble. However, this condition is usually due to the nature and to the chemical composition of the ash.

The root of the flame must be surrounded by incandescent bricks, for the purpose of hastening the ignition and combustion of the coal particles. In this respect, powdered coal differs from other fuels. A stream of gas will readily burn in the open; a stream of well-atomized oil can be made to burn in the open air, but with some difficulty; while a stream of powdered coal will not burn in the open, at least not with any equipment now known to the art.

Another factor which must be considered with powdered coal is the disposal of the ash. Extremely fine ash is carried through the combustion space, through the heating chamber, and through the flues and the stack out into the open air. Coarse ash, on the contrary, should be deposited in the combustion chamber and should not be carried over into the heating chamber. It is quite

evident that the coarseness of the ash particles depends upon the method of grinding and also upon the method of separating coarse and fine particles of coal at the mill. For that reason the size of the combustion chamber, and more particularly its length, should be determined with regard to fineness and uniformity of grinding, although in practice, this is seldom done. While, in general, the statement holds that the combustion space must be large enough and long enough to have the coarse ash particles drop before they reach the bridgewall, this rule has sometimes been disregarded in continuous furnaces for billet heating. In some furnaces which have come under the observation of the author the fine ash is blown off at regular intervals by means of a steam jet, at those sections of the steel which are still cold enough to prevent the ash from sticking. For reasonably complete combustion, from 3 to 7 B.t.u. is the limit of heat which can be liberated each second per cubic foot of combustion space, when powdered coal of average fineness is used in single-stream burners. But combustion volume is not the only requisite. Length of path of combustion must likewise be considered. With average fineness and with burners feeding from 800 to 2000 pounds of coal per hour, a length of $4\frac{1}{2}$ to $5\frac{1}{2}$ feet suffices, provided the flame is so directed that it will not strike any brickwork in less than that distance.

The problem of ash disposal in the combustion of powdered coal causes a peculiar dilemma. If a separate, large combustion chamber is provided, the ash is dropped in it, and practically none passes into the heating chamber; but the combustion chamber becomes overheated, the brickwork is heated to the melting point, and the heating chamber is comparatively cold. If, on the other hand, combustion is allowed to reach into the heating chamber, ash is deposited upon the heating stock. The latter trouble might be avoided by burning the coal to CO in the combustion chamber and by introducing secondary air at the bridgewall. This scheme may become of importance, although it has, as yet, not been used as far as the author knows. Most practical designs are compromises; most of the heavy ash and unburned coke particles are dropped in the combustion chamber, and only fine ash is deposited on the heating stock.

The difference between boiler furnaces and industrial furnaces may be emphasized at this time. In the former, a slight vacuum,

or "draft," exists. Delayed combustion and cooling of the refractory walls are both obtained by the admission of air through adjustable port holes which are scattered along the path of the flame. These port holes may be left open, because of the draft. Excessive temperature concentration is avoided by this expedient. In the combustion chamber of an industrial furnace a slight pressure exists, and scattered port holes could be served only by a network of pipes coming from a blower, or else by surrounding the combustion chamber with a wind box which is subjected to pressure. In either case, the regulation of the various port holes, and the regulation of the flame through them, is difficult. For

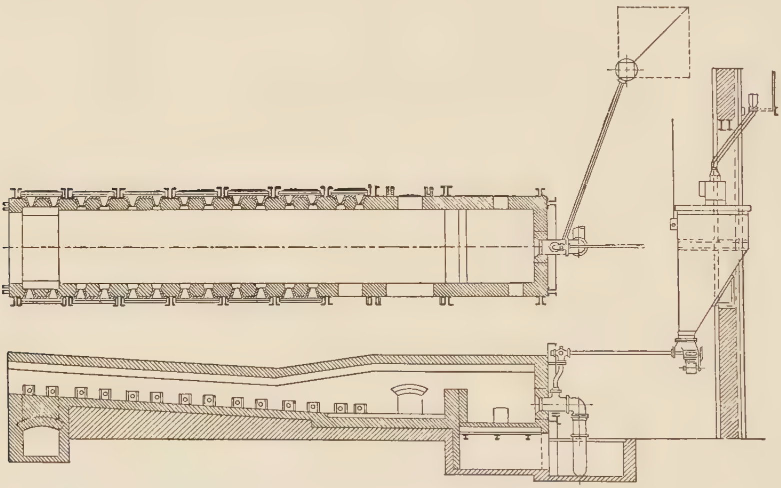

FIG. 108.—Continuous furnace for powdered coal firing.
Note simple rectangular combustion chamber and unrestricted radiation to burner outlet.

that reason the design of boiler furnaces has not been adopted for industrial furnaces.

An additional difference consists in the method of coal injection. With boiler furnaces it has become customary to inject the coal dust from above and to compel the flame to bend backward upon itself because of the buoyancy of the heated gases. This design is very good if a draft exists in the furnace; it offers some difficulties if a pressure exists in the combustion chamber, as is the case in industrial furnaces. This problem is discussed below.

It will be of interest to examine the combustion spaces of

some furnaces with a view to finding out to what extent the above considerations are being used in practice. It will be noted that the combustion space of Fig. 108 is of simple rectangular shape, and that radiant heat can reach back to the burner mouth, where quick and reliable ignition is needed. Figure 109 also illustrates the same principles. Although the combustion chamber of Fig. 110 offers nothing new compared with those of Figs. 108 and 109, the illustration is offered on account of other interesting features. It represents a continuous annealing furnace in which

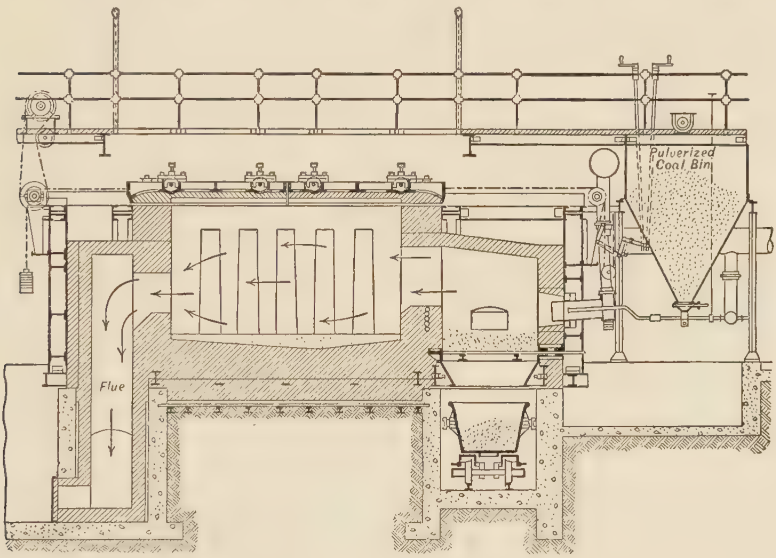

FIG. 109.—Soaking pit for powdered coal firing.

Note rectangular combustion chamber and free access of radiation to burner outlet.

sheets or tin plates pass over rollers. Ashes are deposited on the sheets, but not to a great extent, because the sheets pass through the furnace quite rapidly.

In small furnaces it is quite difficult to secure the necessary flame length and to keep the flame from impinging upon the walls before combustion is complete. Extreme uniformity and fineness of grinding help in such a case. To a certain extent, the difficulty has been overcome by arranging two burners opposite each other, as shown diagrammatically in Fig. 111. The two jets, impinging upon each other, form a disk of fire.

A discussion of the combustion chamber would not be complete without some reference to the question: Vertical or horizontal burner? In the United States industrial furnaces have been almost exclusively equipped with horizontal burners, whereas in

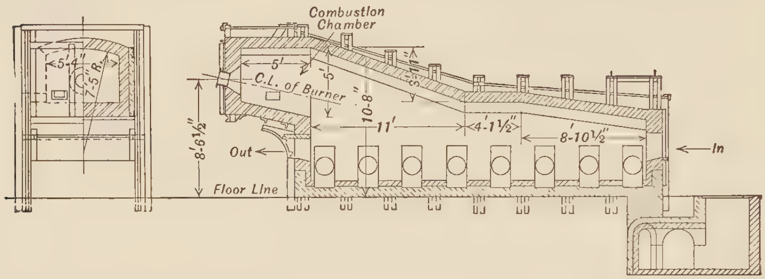

FIG. 110.—Continuous annealing furnace fired with powdered coal through a single burner. Combustion chamber and heating chamber adjoining, without any separating wall.

Germany and also in England the vertical burner is preferred. Figure 112 shows an English billet-heating furnace with unit pulverizer, while Fig. 113 illustrates a Continental furnace with almost vertical admission of powdered coal and air. The intention in the use of the vertical burner is to project heavy ash and coke particles to the floor of the combustion chamber and to prevent their being carried into the heating chamber. The admission of secondary air must be studied quite carefully, if the vertical burner is to be successful. Secondary air cannot enter around the mouth of the burner because of the furnace pressure. It must be admitted near the hearth level or, better still, below the hearth level. If vertical admission of coal dust and primary air is practiced in connection with industrial furnaces the primary air will probably have to equal more than 50 per cent of the total combustion air.

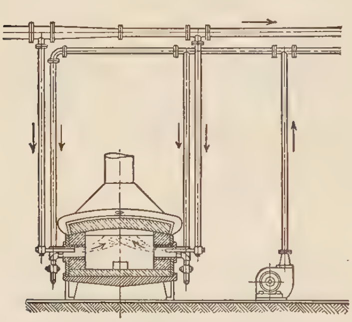

FIG. 111.—Powdered-coal-fired furnace with opposite impinging jets.

Flame intensities and flame lengths can be varied with powdered coal in very much the same manner as with oil and gas.

Thorough mixing of the coal dust and secondary air produces comparatively short (4 to 6 feet) flames, while absence of turbulence produces long, lazy flames of comparatively low temperature. A smaller flame in a large furnace likewise results in low furnace temperature, particularly if there is recirculation of the products of combustion.

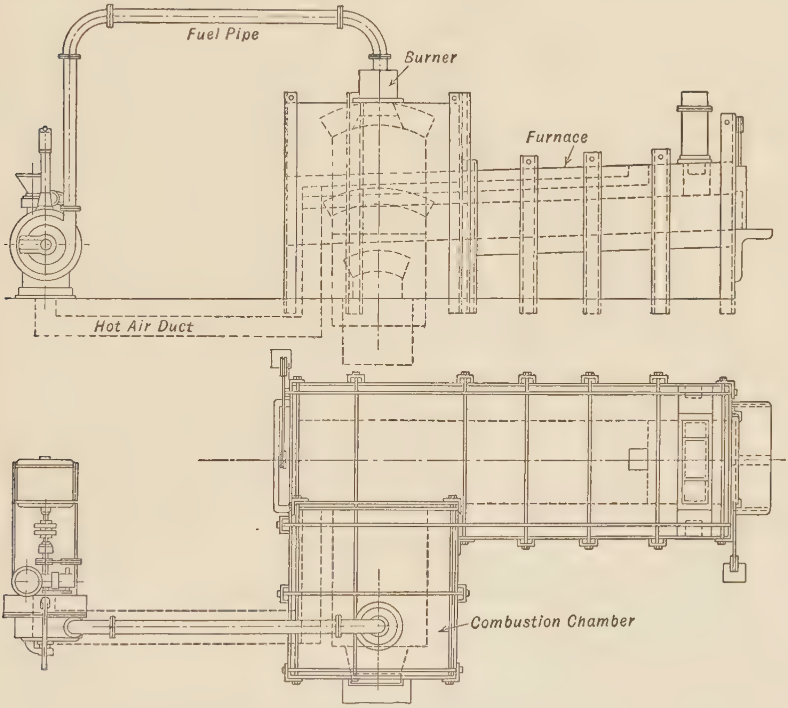

FIG. 112.—Billet-heating furnace fired by powdered coal.

Note vertical burner on combustion tower and unit pulverizer taking preheated air from furnace.

Aside from the difficulties with ash, discussed above, most of the troubles which have been encountered in the development and application of powdered coal have been caused by non-uniform heating. Attention has been concentrated to such a degree upon burning the pulverized fuel properly that it has often been largely diverted from the equally important problem of applying the heat, thus developed, uniformly to the materials being heated. From the physics of combustion of powered coal it is evident that a uniform temperature is difficult to obtain

over a large hearth with that fuel, except by the method of the "lazy flame," or by a good circulation of the gases. In continuous furnaces, the problem is comparatively simple because of the progressive motion of the heating stock.

It may not be amiss to call attention to the proper location of burners and feeders, although this is almost self-evident. Radiation from the combustion chamber must not be allowed to heat the burners and feeders to such an extent that the coal will become sticky and cause clogging.

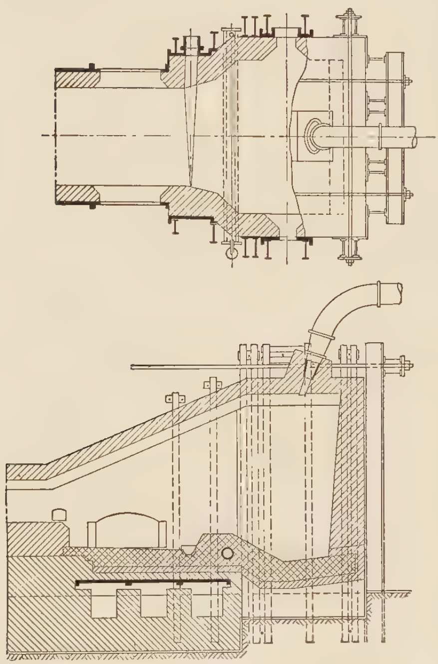

FIG. 113.—Combustion chamber for powdered coal, with nearly vertical admission of mixture. It forms part of a furnace for heating slab ingots.

ELECTRIC HEATING ELEMENTS (RESISTORS)

Methods of Electrical Heating.—Any material through which an electric current flows is heated thereby. The rate at which heat is generated in unit time and in unit volume of the material depends upon the current density, and upon the specific resistance of the material, which will hereafter be called a "resistor." The temperature which the resistor assumes depends upon the rate of heat generation and upon the rate of heat abstraction. By a judicious balance between these two actions, the resistors, or heating elements, can be used through a very wide range of temperatures.

Electrical energy can be utilized for heating purposes in industrial furnaces in several ways:

(1) The material to be heated serves as resistor.

(2) Separate heating elements transfer heat to the stock or charge by radiation and convection; in this case,
 (*a*) the heating elements are in the heating chamber, or
 (*b*) the heating elements are separated from the heating chamber by a muffle wall.

(3) The material is heated by induction currents.

Heating elements may be metallic or non-metallic. If they are metallic, they are cast, rolled, or drawn.

The Material to be Heated Serves as Resistor.—For certain purposes this method has been developed to a high state of perfection. It originated with simple machines for heating rivets, and was gradually extended to the heating of bolts for heading and longer bars for forging. The principle is the one that was used long ago by Thompson for electric welding. The part to be heated is in the low-tension circuit of a stepdown transformer. The time of heating the steel varies with its dimensions and electrical resistance, and with the electrical and magnetic characteristics of the heater. Uniformity of gage or cross-section is closely related to uniformity of heating by this method Rivets below $\frac{1}{2}$ inch diameter are heated in about 20 seconds. Those of $\frac{3}{4}$ to 1 inch diameter require not quite a minute, while larger ones require proportionally more time. A rivet heater is illustrated in Fig. 114. As previously mentioned, the principle has been extended to the local heating of bars for upsetting or forging. A machine for that purpose is shown in Fig. 115. It has also been used for the heating of bars up to 4 feet long. Bars $\frac{3}{4}$ inch in diameter and 4 feet long are heated to 1800° F. in 1 minute and 20 seconds. The energy consumption ranges between 15 and 18 kilowatt hours per 100 pounds of metal heated. A machine for heating long bars is shown in Fig. 116. A movement of the foot treadle brings the piece to be heated to the electrodes. The next movement of the treadle allows the bar to be removed, and then brings the next bar to the electrodes. Electrically heated bars are hotter in the center than at the surface. The principle under discussion is limited to bars of constant cross-section, except in those cases where the lower temperature, prevailing at the points of greater cross-section, is sufficiently high.

Experiments are under way to heat moving, endless welded bars or rods going to forging machines. Up to the time of this writing, the problem has not been successfully solved because of the difficulties of sending extremely heavy currents through a movable joint. The incentive for accomplishing this feat is very great, because it would allow continuous feeding of endless bars to forging machines, and would do away with the waste which now occurs at the beginning and at the end of each bar as it enters and leaves the forging machine. The problem may eventually be solved by the use of the induction type of furnace.

FIG. 114.—Electric rivet heater.

An attempt has also been made to use both the material to be heated and the packing in which it is imbedded as a resistor, with particular reference to hardening furnaces, in which the material to be hardened was packed in a hardening compound, and the whole mixture of charge and hardening compound was subjected to a pressure for the purpose of making the hardening compound a conductor of electricity. As far as the author knows, the scheme has been abandoned because the work was irregular. Obviously, it seems very difficult to distribute the charge through the hardening compound in such a manner that absolute uniformity of temperature and of current is obtained. In any process in which extreme care on the part of the workman is required for obtaining good results, poor work will sometimes

be done, because that care is not always forthcoming. This is probably the reason why the scheme just described, although otherwise very attractive, has been abandoned.

Non-metallic Resistors.—Non-metallic resistors, such as granulated carbon, are sometimes used in industrial furnaces. They have the desirable property of producing a reducing atmosphere, because the glowing carbon burns to carbon monoxide. On the other hand, this very fact caused the carbon resistor to be abandoned, for furnaces of small capacity, in favor of the metallic resistor; the carbon gradually disappeared, and the resistor boxes

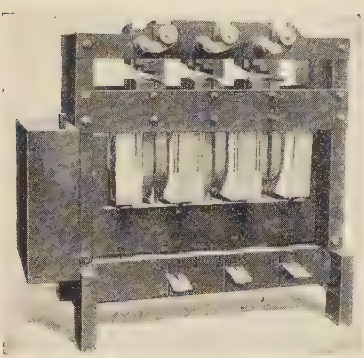

FIG. 115.—Electric heater for short bars.

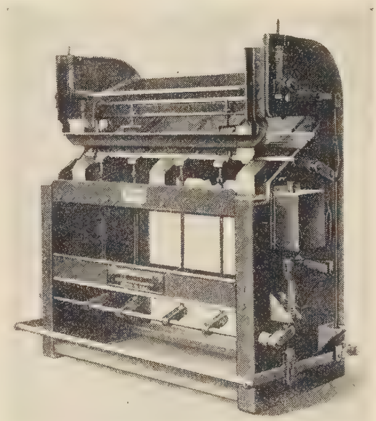

FIG. 116.—Electric heater for long rods.

had to be filled up at intervals. This work has to be carefully done and requires attention, while the metallic resistor requires no attention whatsoever, until it burns out.

The carbon element, however, can be operated at a higher temperature than the metallic resistor, with higher rate of heat transmission per unit of wall surface. For large capacities and higher temperatures, therefore, and in all cases where brass is to be melted, the carbon heating element is indicated, although the carbon resistor is hard on the brickwork, unless highly refractory material is used. Carbon resistors have been used in electrically heated soaking pits.

Another form of resistor now in use consists of bars of a

material composed largely of silicon carbide, with specially treated low-resistance terminals. These resistors are suitable for temperatures up to 2600° F., and can be operated at 3000° F. for short periods, without injury. The material has a very low coefficient of expansion, is mechanically strong, and has a high

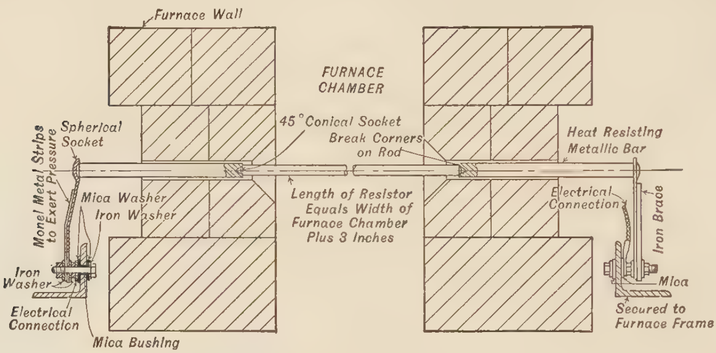

FIG. 117.—Mounting of silicon carbide resistor in furnace.

specific resistance, permitting great concentration of heat in a given space. Figure 117 shows how such a resistor is mounted in a furnace. The monel metal springs and iron braces of the terminals become overheated and yield, if the bars are used in forge furnaces and the like. Water cooling of the terminals then becomes a necessity.

The resistor in question has lately been standardized to some extent. It is made in lengths from 6 inches to 60 inches, and in diameters from $\frac{1}{4}$ inch to $\frac{3}{4}$ inch. It can be used either horizontally

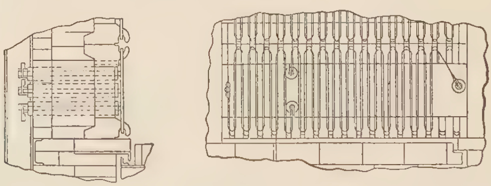

FIG. 118.—Ribbon resistor mounted on furnace wall.

or vertically, and does not soften at 3000° F. The minimum resistance of the bars is 9.0 ohms per one inch length and $\frac{1}{16}$ inch diameter. The maximum resistance for temperatures between

2500° and 2700° F. is 12 ohms per one inch length and $\frac{1}{16}$ inch diameter. For temperatures between 1800° and 2500° F. the resistance may run as high as 20 ohms per one inch length and $\frac{1}{16}$ inch diameter.

Metallic Resistors.—Metallic resistors, as before stated, are cast, rolled, or drawn. The material to be employed depends somewhat upon the temperature at which the resistor is to work and also upon the nature of the furnace atmosphere. For low

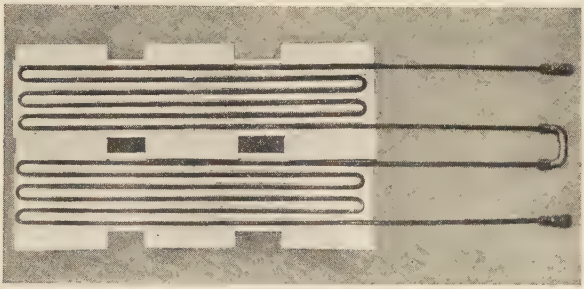

FIG. 119.—Grid resistor made of round wire.

temperatures, iron wire or ribbon is quite satisfactory. Iron is likewise very satisfactory for any temperature short of the melting point of iron, if the furnace is either evacuated or filled with a neutral gas, such as hydrogen, helium, or nitrogen. For temperatures up to 1200° or 1400° F. alloys of nickel, chromium, and iron are used. The higher the temperature at which the resistor is to work in air, the smaller must be the iron content. For temperatures of the resistors up to 1800° to 1900° F. an alloy consisting of 80 per cent nickel and 20 per cent chromium is the material which is universally employed. It may be in the form of a ribbon, as shown in Fig. 118, or in the shape of a flat grid made of round wire, as shown in Fig. 119, or else in the shape of a coiled wire, as shown in Fig. 120. It is also being used in cast grid sections, as indicated in Figs. 121 and 122. In very small furnaces such as are common in laboratory work, the heating element is used in the form of one continuous wire which is coiled on the outside of a muffle; the latter is usually made of alundum.

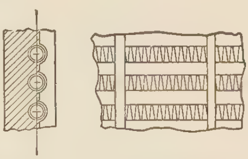

FIG. 120.—Coiled wire resistors.

In all of the designs of metallic resistors or heating elements it is very necessary to avoid local overheating, particularly in furnaces working with resistor temperatures close to that which leads to destruction. The desire to keep the resistor temperature down to a minimum has led to the use of the unmuffled furnace, that is to say, to the use of the resistor in the heating chamber. Referring back to Fig. 118, which shows the design in question, it will be noticed that ribbons are suspended from plugs which are fastened in the wall. The plugs are usually made of alundum or of kaolin. Their shape, together with that of the protecting knobs, is clearly shown in Fig. 123. Since the resistor expands with rising temperature, the ribbon is particularly well adapted

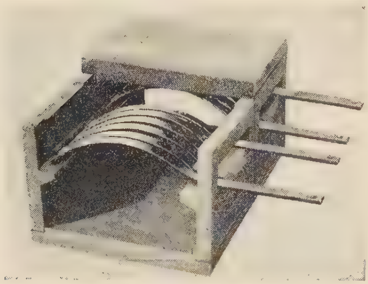

Fig. 121.—Arched grid resistor (cast).

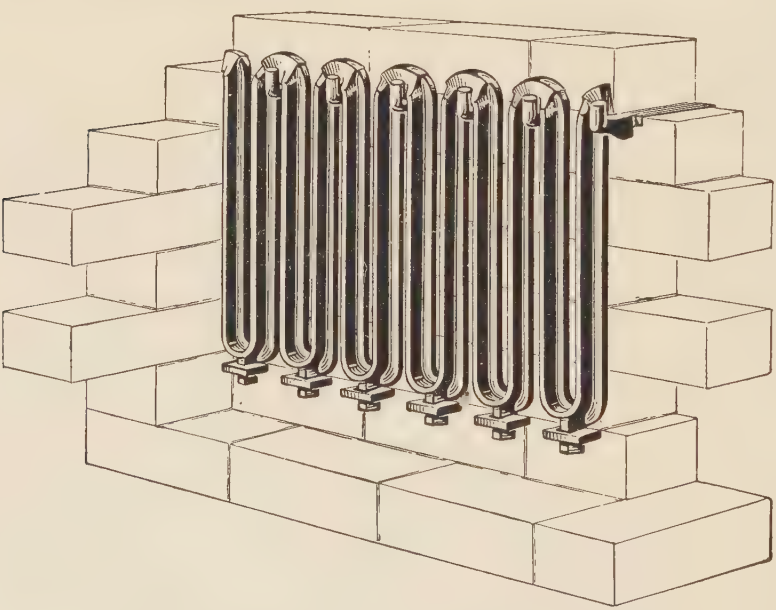

Fig. 122.—Cast grid resistor mounted on sidewall.

to being suspended along the sidewalls of the furnace. It has been used under arches, but, as before stated, the ribbon has a tendency to sag at high temperatures. For that reason, it should not be used under arches unless special methods of support are used, or unless the furnace temperature is low. Sagging and drooping may be prevented by proper supports or cleats. The higher the desired furnace temperature, the more closely these should be spaced. A design in which a porcelain pin supports hairpin coils of round wire is illustrated in Fig. 124. If a ribbon is made quite stiff, and if the span is short, the resistor can be located under the roof. In that case, provisions for easy and quick renewal are desirable. Figure 125 shows such provisions. The ribbon was placed above the material to be heated, and was, for the purpose of quick renewal of burned-out sections, covered by a bung top arch. The latter element of design offers difficulties on account of the weight to be handled and on account of the

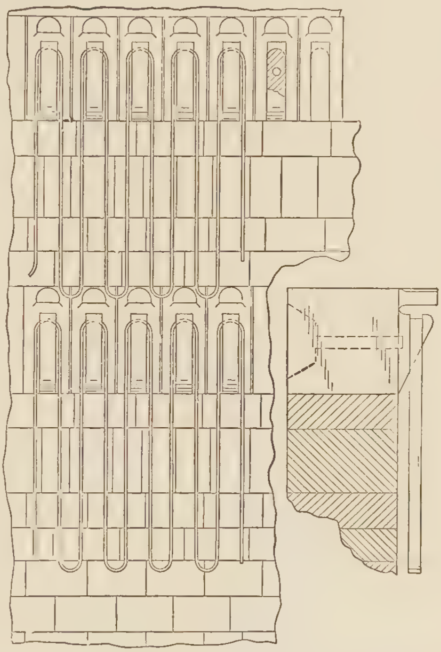

FIG. 123.—Ribbon resistor mounting, with supporting plugs and projecting knobs.

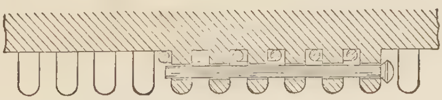

FIG. 124.—Hairpin resistors held by porcelain pin.

special furnace binding which it requires. In consequence, the arrangement of Fig. 125 was soon replaced by that of Fig. 126, in which the ribbon rests on corrugated refractory supports which in

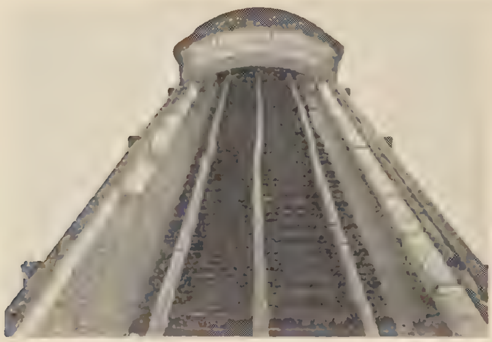

Fig. 125.—Ribbon resistors at top of heating chamber.
Note self-contained, removable roof.

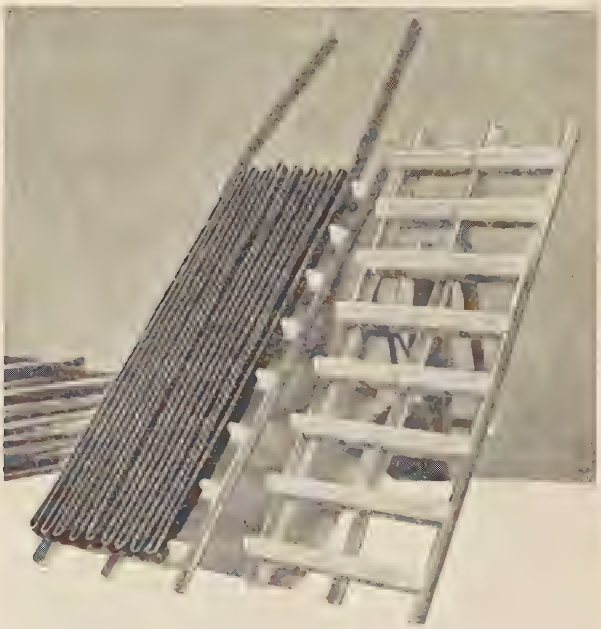

Fig. 126.—Ribbon resistor with corrugated refractory supports and alloy frame.

turn are carried by an alloy frame. The assembled combination can be withdrawn through a side opening in a manner similar to that of Fig. 126*a*. Ribbon elements have been placed under the hearth, and coils of round wire are quite commonly imbedded in the hearth. Resistance elements of the hairpin type placed in the hearth are shown in Fig. 127, which illustrates a car-type furnace. In such designs, the elements are covered with plates of heat-resisting alloys.

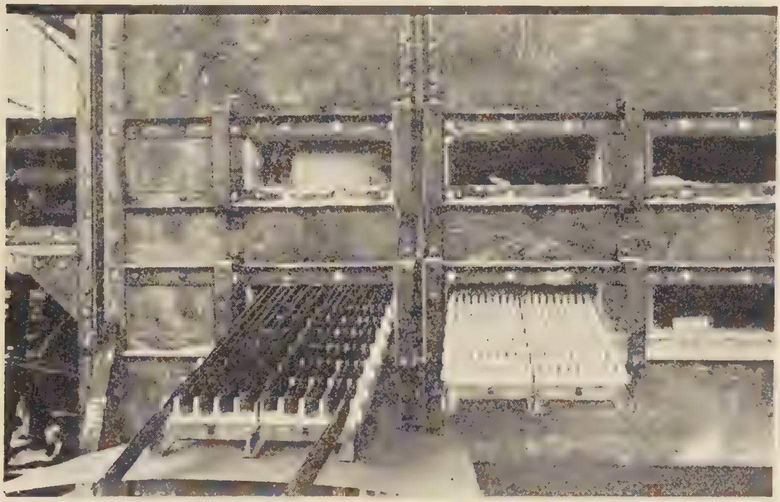

FIG. 126*a*.—Method of withdrawing resistor frame through side of furnace.

The use of the ribbon resistor or any other resistor in an unmuffled furnace gives rise to some danger of accident to the heating element. For instance, part of the charge may roll off, because of heat expansion or vibration, and may fall against the resistor material; or a workman may reach in with a pipe or a rod for the purpose of rearranging the stock in the furnace. Steps have been taken to overcome such troubles. For the protection of the attendants a safety switch has been arranged in such a manner that the current is interrupted as soon as the door of the furnace is opened.

The other trouble, namely, the possibility of part of the charge, through vibration or expansion, becoming loose and rolling

over to the side of the furnace where it may touch the resistors and cause a short-circuit, is somewhat harder to overcome.

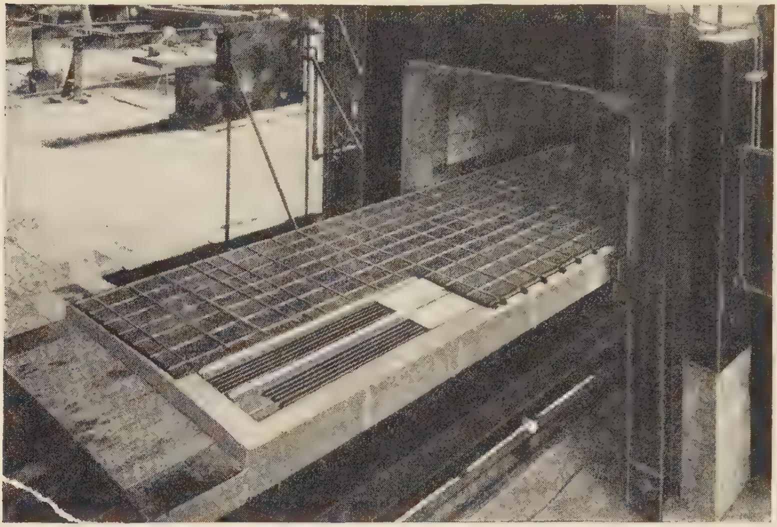

FIG. 127.—Hairpin resistors placed under hearth.

Note cover plates; these are of heat-resisting alloy.

There are designs, such as that shown in Fig. 128, in which the resistor is set back on a ledge and the door is made somewhat narrower than the hearth, both of which features make for safety, inasmuch as material rolling off a tray would probably not reach the resistors. Recently, one of the furnace builders has put diamond-shaped plugs between the ribbons, in such a manner that they extend beyond the ribbons and prevent the material of the charge from coming in contact with them. While this design is a great deal safer than the other, it still leaves the possibility that projections on parts of the charge may slip in between the kaolin plugs

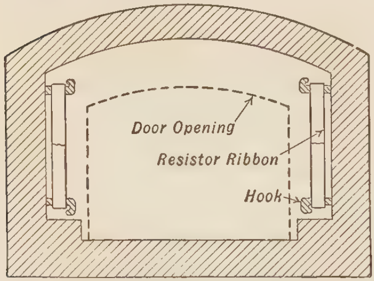

FIG. 128.—Arrangement of resistor to reduce chance of work touching ribbon.

Note that resistor is set back on a ledge and door is narrower than hearth.

and touch the resistors. However, that possibility is rather remote.

The arrangement of the diamond-shaped protecting plugs is shown diagrammatically in Fig. 129. It is quite evident that the protecting plugs will interfere to some extent with the radiation of the ribbon into the furnace. For that reason the rate of heat emission per square foot of sidewall per hour is somewhat lower with the protecting plugs in place than it is without them. Without the plugs, the rate of heat or energy emission is $2\frac{1}{2}$ to 3 kilowatts per square foot of sidewall, in the case of heat-treating or enameling furnaces. If protecting plugs are used, the rate must be somewhat smaller.

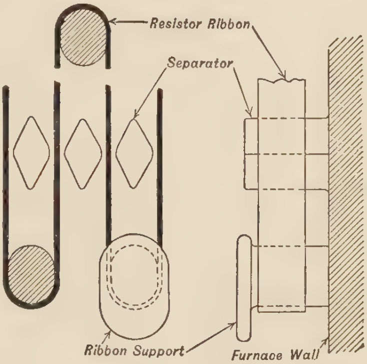

FIG. 129.—Ribbon resistor with protecting plugs to prevent work from touching resistor.

The necessity for protecting the resistors from contact with the material being heated probably was the prime reason for the design illustrated by Fig. 130, in which round resistors of the hairpin-loop type are located at the bottom of grooves in the refractory lining.

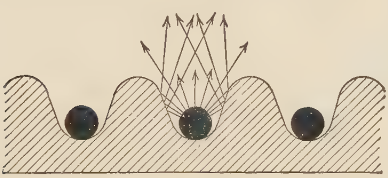

FIG. 130.—Resistors of the return-bend type, located at the bottom of grooves in the furnace lining.

Note direction of radiation and reflection of heat.

In some cases a perforated muffle has been used in front of the heating element near the hearth, for the purpose of protection, both from mechanical injury and from short-circuit. Such an arrangement is shown in Fig. 131.

Cast resistors, such as shown in Figs. 121 or 122, and ribbons supported as in Fig. 126 have the advantage of rigidity, in consequence of which they can be placed in the furnace wherever necessary, either above or below the charge or between the parts of the charge. A furnace for the annealing of piston rings, showing heating elements both above and below the charge, is

illustrated in Fig. 132. It is claimed that the specific resistance of cast resistors is not as constant as that of rolled or drawn resistors.

The desire to protect the heating elements from mechanical injury, so as to prevent short-circuits, and also to protect them from the influence of vapors (sulphur corrodes nickel-chromium very quickly), has caused engineers to adopt muffle resistors for certain purposes. A design using muffled resistors is shown in

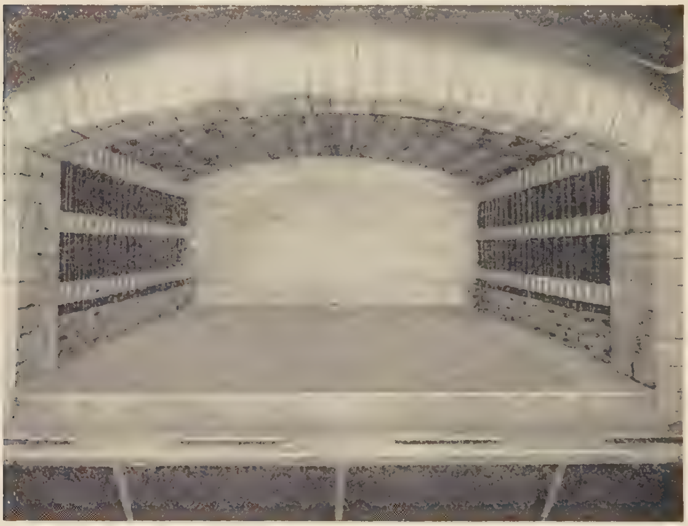

Fig. 131.—Resistor elements protected by perforated muffle near hearth.

Fig. 133. In this furnace design T-shaped bricks are built into the furnace wall. These bricks retain slotted cleats, in the grooves of which the wire grids are held. Another design, in which the resistors can be used either muffled or unmuffled, is shown in Fig. 134, which represents part of the side wall of a pit furnace. Muffle plates can be slipped behind the projecting ledges and in front of the wires.

The sections of wire or ribbon are joined together inside the furnace chamber, either by welded connectors of large cross-section or by the so-called oxide connector (Fig. 135). The latter consists of a cold-rolled steel sleeve pressed into a nickel-

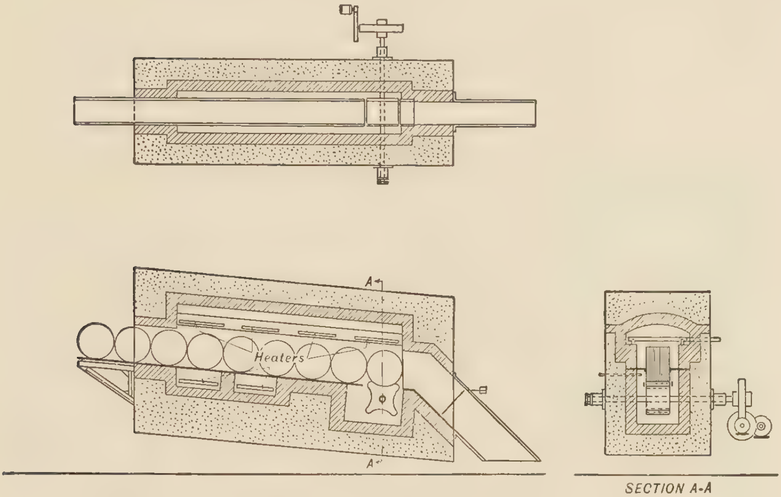

FIG. 132.—Electric furnace for annealing piston rings.
Note heating elements both above and below the charge.

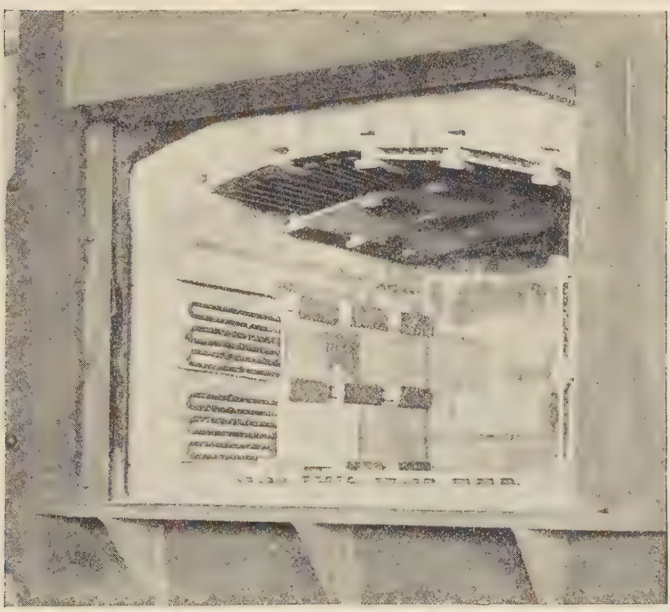

FIG. 133.—Muffled resistors of the hairpin type.

chromium sleeve. Two set screws serve to hold the coil in position until the furnace is heated up. As soon as the connector is heated above 750° F. the cold-rolled steel oxidizes rapidly; and it is well known that the oxide of iron occupies a larger volume than that of the iron itself. Consequently, the oxidized sleeve expands, presses tightly against the wire on the inside, and the solid nickel chromium sleeve on the outside, and thus makes a firm fit. The joint is indestructible, and its conductivity, in many cases, is superior to that of a weld. This makes a very convenient method of connecting coils inside the furnace chamber. It is very much easier to remove than a weld, since it is merely necessary to saw the outside connector in two lengthwise, in order to remove it. This means that the original length of the coil is retained, whereas if a welded connector is used, it is necessary to cut off some of the coils in order to remove the connector.

FIG. 134.—Sidewall of pit furnace, with hairpin resistors. Resistors can be muffled by slipping muffle plates between the wires and the projecting ledges.

The controversy which exists at the time of the writing of this book concerning the relative merits of muffled, semi-muffled, and unmuffled resistors for furnaces, is undoubtedly due to the use of the nickel-chromium heating element in high-temperature furnaces, to which it is not suited, as their temperature comes close to the limit which the nickel-chromium element can endure. In the future new kinds of material will doubtless be used as resistors for high temperatures, and the question of muffled or

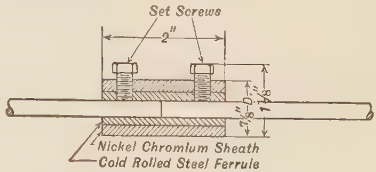

FIG. 135.—Iron-oxide connector.

unmuffled resistors will lose much of the interest which it holds at the present time. In this connection it will be interesting to note that in *Feuerungstechnik*, March 15, 1924, there appeared a description of a new material which may solve the problem of furnishing a high-temperature resistor. This material, which is called Keramonite, is a cross between a metallic resistor and a ceramic resistor. It consists of a metallic skeleton which is imbedded in a new ceramic material and which has been burned at high temperature. This material can be made in strips or ribbon which can be coiled without the breaking of the ceramic part. It is stated that these strips will stand a temperature of 3000° F. without any injury. In the United States a resistor consisting of metallic tungsten imbedded in zirconium oxide has been patented. While it is yet too early to predict the future of such materials, it is safe to say that a material other than nickel-chromium will doubtless be used in the future for high-temperature work. Attention is also called to Fig. 117 of this chapter, which illustrates a non-metallic resistor for high temperatures.

Capacity of Heating Elements.—It is usually cheapest to impress the line voltage upon the resistor. The voltage used for this purpose may be 110 volts, 220 volts, or even higher. If line voltage cannot be used, on account of its requiring too thin a ribbon or wire, it becomes necessary to use transformers which, of course, increase the cost of the installation. In any case it is necessary to make the resistor of sufficient length and of the right cross-section to give that total resistance which will heat the wire to the required temperature and allow the heat to be properly carried away. In the catalogues of reliable makers of resistor material, whether it be in the shape of round wire or of flat ribbon, there are usually given the ohms per foot of length for the different sizes of wire and of ribbon. Frequently there are also given the amperes which will heat straight wire or coiled wire to various temperatures in air. As a rule the resistor must be so designed that it will heat the furnace to a slightly higher temperature than the one desired. The desired temperature is then maintained by control devices, which turn the power on and off, as required, during regular operation. It is evident that the amount of energy which can be given off by a resistor varies with the furnace temperature. The temperature at which the resistor can operate is determined by the material of which it is composed.

The amount of heat energy which a unit area of the surface of the resistor can radiate depends upon the absolute temperatures of the resistor and of the furnace. The calculation of this rate of energy transmission is somewhat complicated and tedious, because it involves the difference of the fourth powers of the absolute temperatures. For that reason a curve such as the one shown in Fig. 136 is very handy for practical purposes. It is correct only for a given spacing of the wires.

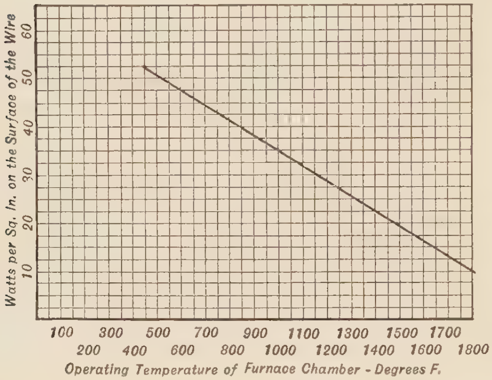

FIG. 136.—Curve showing relation between furnace temperature and safe values of heat emission from resistors. Applies to heating elements fully exposed to furnace chamber with no muffle or other interference.

The relation between the maximum safe temperature of the resistor, the temperature of the furnace, and the rate of heat transfer from a square foot of resistor-covered wall surface can be studied from an idealized case. Suppose the wall to be completely covered with a thin ribbon or wire. Then all of the heat is given off by a surface which equals the wall area and is equal to

$$0.15\left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right] \text{B.T.U. per hour and square foot,}[1] \quad (8)$$

[1] The radiation coefficient for nickel-chromium wire is not very definitely known. In a hot furnace with all parts of the interior at nearly the same temperature, differences of emissivity disappear, and the condition of "black body" radiation obtains (see Volume I, page 19). With a cold charge in a hot furnace, however, the differences of emissivity of the heat-radiating and heat-receiving surfaces must be taken into account. The coefficients appear to vary with the temperature as well as with the material and the roughness of the surfaces, approaching more closely the "black body" coefficient the higher the temperature. For resistors of the usual type, radiating to dull, moderately rough iron surfaces, the coefficient has been taken as 0.15 instead of 0.162, the "black body" value; under usual conditions of heating, the error is negligible.

where T_1 = absolute resistor temperature and T_2 = absolute temperature of the charge in the furnace. Expressed in kilowatts, this becomes

$$\frac{0.15 \times 778 \text{ ft.-lb./Btu.}}{60 \times 44{,}250 \text{ ft.-lb./kw.-minute}}\left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right]$$

$$= 0.000044\left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right] \text{kw. per sq. ft.} \quad . \quad . \quad (9)$$

From this equation the following tabulation was computed:

TABLE XV

Ideal Rate of Heat Transfer from One Square Foot of Electrically Heated Wall

Furnace temperature, degrees F.	Temperature of resistor—Degrees F.					
	1600	1700	1800	1900	2000	2200
1200	4.6 kw.	5.8 kw.	8.1 kw.	10.3 kw.	12.7 kw.	18.7 kw.
1300	3.8	5.3	7.2	9.5	11.8	17.3
1400	$\boxed{2.7}$	4.4	6.2	8.3	10.7	16.7
1500	1.4	$\boxed{3.2}$	5.0	7.2	9.6	15.5
1600	0	1.7	$\boxed{3.5}$	5.8	8.2	14.0
1700	....	0	1.9	$\boxed{4.1}$	6.5	12.4

It is interesting to note the extent to which the safe upper temperature limit for continuous heating of the resistor affects the rate at which heat can be sent out from a square foot of heating surface.

In practice, the rate seldom exceeds 60 per cent of the values of the tabulation, because it is impossible to cover the wall uniformly with a resistor; furthermore, there will always be hot spots in the resistor behind fasteners, as can be seen from Fig. 137 (which also illustrates the method of connecting hairpin resistors). In consequence, the average temperature of the resistor will be below its safe temperature. Finally, the temperature of the wall between the strands of heated resistors is below the temperature of the latter.

In the tabulation, the combinations in which the resistor temperature exceeds the furnace temperature by 200° F. have been enclosed in frames. It is not advisable to have the difference between resistor temperature and furnace temperature much greater than 300° F., because of the possibility of overheating the surface of the charge, particularly if some pieces lie close to the heating elements.

The refractories used in electric resistor furnaces must have a very low coefficient of expansion and very high electric resistance.

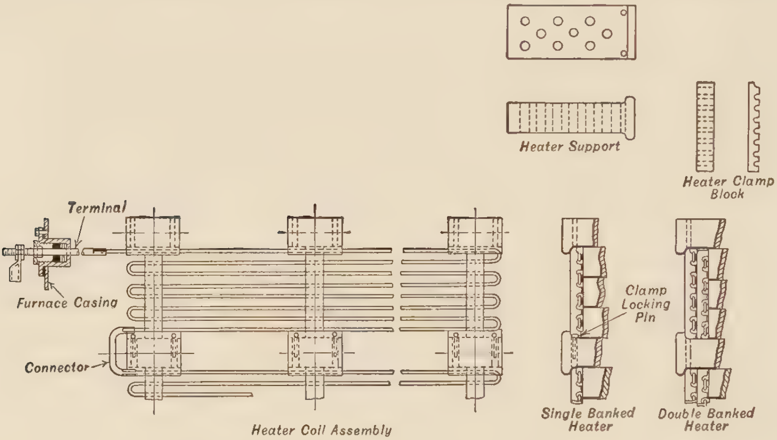

FIG. 137.—Assembly of heating elements of the hairpin type. Note supports, and method of making connections.

On the other hand, they should have high thermal conductivity, especially where they are used to keep the coils or ribbon in place and are therefore required to dissipate the heat from sections of the resistor passing through them or around them. They should contain no mineral elements which might give off injurious gases when heated. They should be strong and durable, to sustain the mechanical shocks received. The hangers supporting the ribbons or elements should have smooth surfaces at the place of contact, in order to avoid abrasion due to expansion and contraction of the elements.

As electrically heated furnaces are usually purchased complete from manufacturers experienced in this class of work, very few engineers will have occasion to calculate the sizes of resistors for given conditions. Nevertheless, cases will arise in which it is

either impossible to use a standard furnace, or in which an electrical resistor must be rigged up in a hurry. In such cases an example illustrating the computations used in the design of electric resistors will be of considerable assistance. Therefore, a computation of length and cross-section of wire or ribbon to suit given conditions will now be presented.

Example.—Let it be required to design resistors for a furnace having two sidewalls 6 ft. long and $2\frac{1}{2}$ ft. high. The maximum capacity of the furnace is to be determined by the fact that walls give up heat at the rate of 3 kw. per square foot of wall surface per hour. The furnace temperature is to be 1600° F., and the voltage is 110 volts. It is required to determine the size of unmuffled ribbon, that is, its length and cross-section, and also the size of round wire if a muffled furnace is used.

The area of one sidewall equals $6 \times 2\frac{1}{2} = 15$ sq. ft. The calculations will be made for one wall only, a duplicate resistor set being required for the opposite wall.

$$15 \text{ sq. ft.} \times 3 \text{ kw./sq. ft.} = 45 \text{ kw.}$$

$$\frac{45 \times 1000}{110 \text{ volts}} = 410 \text{ amperes current flowing through resistor.}$$

$$\text{Required resistance} = \frac{110 \text{ volts}}{410 \text{ amperes}} = 0.27 \text{ ohm.}$$

The resistance may be all in series, or in several circuits in parallel. Several arrangements will be figured, for the purpose of selecting the most suitable.

Since the carrying capacity of the wire is affected by the relations of the temperature of resistor, of furnace, and of charge, it will be advisable to study these relations, referring to Fig. 138. Some doubt may exist about the meaning of "furnace temperature." This is really the temperature of the furnace walls as shown by the pyrometer connected with the temperature-controlling device, and, depending upon the location of that device, may be anything between the limits of temperature of charge and temperature of resistor. Usually the final furnace temperature is only slightly above the final temperature of the charge. When the desired furnace temperature is reached (in this case 1600° F.), at point A, the automatic control acts to cut off the current, and thereafter throws it on and off in such a manner as to maintain the furnace temperature practically constant at 1600° F. The resistor must, then, be so designed that at point B, corresponding to 1600° at point A, the temperature of the heating element does not exceed the safe working temperature of the resistor material, which in this example will be assumed to have a maximum value of 2000° F., for short periods.

For given conditions, the heat emission and carrying capacity of wires and ribbons can be calculated with great accuracy. It is obviously impossible, however, to tabulate the values for all of the possible combinations of resistor temperature, of furnace temperature, and of restricted or free radiation which may be encountered in various types of furnaces. In Table XVI,

TABLE XVI*

B. & S. gage	Diameter in inches	Ohms per foot, straight wire	Amperes to heat straight wire to 600° F. in air	Amperes to heat straight wire to 1200° F. in air	Amperes to heat straight wire to 1800° F. in air	B. & S. gage
2	.258	.00954	72	171	297	2
3	.229	.0121	60	144	248	3
4	.204	.0152	54	121	207	4
5	.182	.0192	45	102	176	5
6	.162	.0242	38	86	149	6
7	.144	.0306	31	72	126	7
8	.128	.0387	26	60	106	8
9	.114	.0488	23	50	89	9
10	.102	.0610	20	43	76	10
12	.081	.0968	14.7	31.3	55.0	12
13	.072	.1225	12.6	27.0	46.0	13
14	.064	.1550	11.0	28.8	39.0	14
15	.057	.195	9.5	19.2	33.0	15
16	.051	.244	8.4	16.6	28.0	16
18	.040	.397	6.6	12.0	20.0	18
19	.036	.490	5.9	10.3	17.3	19
20	.032	.610	5.3	9.2	15.0	20
21	.0285	.769	4.5	8.0	12.8	21
22	.0253	.977	3.9	6.8	10.5	22
23	.0226	1.22	3.4	5.7	9.0	23
24	.0201	1.55	3.0	4.9	7.4	24
25	.0179	1.92	2.6	4.2	6.3	25

* Published by courtesy of Hoskins Mfg. Co., Detroit, Mich.

the carrying capacities are shown for various sizes of wire, freely exposed on all sides, in air—that is, for radiation to surroundings at 60 to 100° F.—and for wire temperature of 600, 1200, and 1800° F. For other conditions, the tabular values must be modified, in the manner to be explained.

The first modification arises from the fact that, when the wires or ribbons are located close together near a wall, the radiation from each section is partly blocked off by the adjacent sections, and is restricted by the wall, which assumes a temperature intermediate between the temperature of the

resistor and that of the charge. The heat-emitting capacity is thereby reduced, in usual designs, to about 75 per cent of the values given in Table XVI.

The second modification is necessitated by the reduction of heat radiation by the rising furnace temperature, as explained on page 147. The temperature at C, Fig. 138, giving a rate of heat emission to the cold charge, or to the atmosphere, equal to the heat emission from resistor at 2000°, to charge at 1600°, is found from the equation

$$0.15\times\left[\left(\frac{T+460}{100}\right)^4-\left(\frac{522}{100}\right)^4\right]=0.15\times\left[\left(\frac{2000+460}{100}\right)^4-\left(\frac{1600+460}{100}\right)^4\right], \quad (10)$$

from which

$$T=1620°\text{ F.}$$[1]

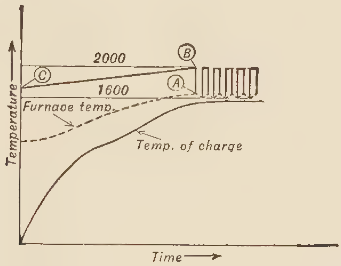

FIG. 138.—Relation of temperatures of charge, of furnace walls, and of resistor or heating element, with automatic on-and-off temperature control.

No tabulation is given for this temperature, but the heat emission relative to wire at 1800° (column 6 of Table XVI) is

$$\frac{0.15\times\left[\left(\frac{2000+460}{100}\right)^4-\left(\frac{1600+460}{100}\right)^4\right]}{0.15\times\left[\left(\frac{1800+460}{100}\right)^4-\left(\frac{522}{100}\right)^4\right]}=72\text{ per cent.} \quad (11)$$

The energy emission to be figured on is then 0.75×0.72, or 54 per cent; but the corresponding tabular value, since the energy developed in a given resistor is proportional to the *square* of the current flowing in it, is $\sqrt{0.54}$ or $73\frac{1}{2}$ per cent of the tabular values in column 6, Table XVI.

The above figures are not absolutely exact, because heat is transmitted by both radiation and convection, and while radiation depends on the difference of the fourth powers of the absolute temperatures, convection varies only as the five-fourths power of temperature difference. At these high

[1] In these calculations, T represents degrees Fahrenheit, *not* absolute.

temperatures, however, radiation is by far the more important factor, and the error in the calculation is negligible.

(*a*) Suppose all of the wire is to be in one section:

Resistance = 0.27 ohm;

Carrying capacity required = 410 amperes;

Tabular value required = 410/(73.5%) = 559 amperes.

The largest-sized wire given in the table has a tabular value of only 297 amperes. A ribbon would have to be used.

In Tables XVII and XVIII are given "comparison numbers" for ribbons and for round wires, respectively. The numbers are not absolute values; they are arbitrary numbers used by one manufacturer of resistance alloys, but are nevertheless directly proportional to the heat emission and current-carrying capacity.

TABLE XVII *

RIBBON AND STRIP COMPARISON NUMBERS

Thickness		Width, inches										
B. & S.	Inches	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1
10	0.102	...	....	....	....	....	5550	7200	8830	10,500	12,150	13,850
11	0.091	...	....	....	....	....	5220	6780	8320	9,850	11,500	13,000
12	0.081	...	....	....	....	....	4900	6380	8050	9,300	10,850	12,350
13	0.072	...	....	....	....	....	4580	6000	7410	8,790	10,200	11,600
14	0.064	...	....	....	....	2980	4280	5650	6950	8,300	9,650	11,100
15	0.057	...	....	....	....	2800	4070	5320	6570	7,950	9,100	10,400
16	0.051	...	....	....	....	2635	3830	5040	6220	7,430	8,620	9,900
17	0.045	...	....	....	....	2460	3590	4730	5850	6,960	8,100	9,250
18	0.040	...	....	....	....	2310	3380	4460	5520	6,620	7,670	8,750
19	0.036	...	....	1165	1675	2190	3200	4240	5250	6,270	7,300	8,330
20	0.032	...	....	1085	1575	2060	3030	4000	4980	5,930	6,900	7,870
21	0.0285	...	....	1020	1480	1940	2870	3780	4700	5,600	6,530	7,450
22	0.0253	...	....	960	1395	1845	2700	3580	4440	5,320	6,185	7,055
23	0.0226	...	482	900	1315	1725	2550	3390	4200	5,025	5,860	6,690
24	0.0200	...	450	844	1240	1625	2405	3200	3970	4,750	5,550	6,320
25	0.0179	...	422	796	1170	1542	2288	3033	3770	4,520	5,275	6,000
26	0.0159	...	395	750	1100	1455	2160	2860	3570	4,260	4,980	5,700
27	0.0142	...	368	698	1040	1370	2040	2700	3360	4,050	4,700	5,370
28	0.0126	...	343	647	971	1290	1910	2540	3165	3,800	4,410	5,050
29	0.0113	173	324	620	916	1220	1810	2410	3000	3,590	4,180	4,790

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As the comparison number of No. 2 wire, from Table XVIII, is 5560, the required comparison number of ribbon, for 559 amperes is

$$(559/297) \times 5560 = 10{,}450.$$

From Table XVII, this corresponds to No. 14 gage ribbon 1 in. wide. From Table XIX, the resistance of such a ribbon when cold is 0.00767 ohm. This is increased 10 per cent when the ribbon is hot, giving 0.00844 ohm.

$$\frac{0.27 \text{ ohm required}}{0.00844} = 32 \text{ ft., length of ribbon required for one side-wall.}$$

(*b*) Two sections in parallel:

$$410/2 = 205 \text{ amperes each section;}$$

$$2 \times 0.27 = 0.54 \text{ ohm, resistance of each section;}$$
$$205/(73\tfrac{1}{2}\%) = 279 \text{ amperes, tabular value.}$$

As the tabular carrying capacity of No. 2 wire = 297 amperes, wire of this size would be suitable.

TABLE XVIII *

Round Wire Comparison Numbers

Diameter, inches	B. & S. gage	Comparison number	Diameter, inches	B. & S. gage	Comparison number
0.289	1	6550	0.051	16	543
0.258	2	5560	0.045	17	460
0.229	3	4720	0.040	18	390
0.204	4	4000	0.036	19	330
0.182	5	3380	0.032	20	279
0.162	6	2860	0.0285	21	236
0.144	7	2420	0.0253	22	200
0.128	8	2050	0.0226	23	170
0.114	9	1736	0.020	24	144
0.102	10	1470	0.0179	25	122
0.091	11	1242	0.0159	26	103
0.081	12	1052	0.0142	27	87.6
0.072	13	891	0.0126	28	75
0.064	14	755	0.0120	...	70
0.057	15	640	0.0113	29	64.4

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TABLE XIX *

Average Resistance per Sq. Mil Ft. = 491 ohms at 75° F. (24° C.) Average Resistance per Cm.^{3} = 104 Microhms at 75° F. (24° C.)
Average Temp. Coeff. (75° F. to 1800° F.) = 0.00006 per 1° F. (0.00011 per 1° C.)
Weight per Cubic Inch = 0.302 lb.

B. & S. gage	Thickness, inches	Nominal area in square mils								Ohms per foot †							
		Width, inches								Width, inches							
		1/32	1/16	1/8	1/4	3/8	1/2	3/4	1	1/32	1/16	1/8	1/4	3/8	1/2	3/4	1
14	0.064	....	......	......	16,000	24,000	32,000	48,000	64,000	....	.....	......	0.0307	0.0204	0.0153	0.0102	0.00767
15	0.057	....	......	......	14,250	21,400	28,500	42,800	57,000	....	.....	......	0.0344	0.0230	0.0172	0.0115	0.00861
16	0.051	....	......	......	12,750	19,130	25,500	38,260	51,000	....	.....	......	0.0385	0.0256	0.0193	0.0128	0.00963
17	0.045	....	......	......	11,250	16,880	22,500	33,760	45,000	....	.....	......	0.0436	0.0292	0.0218	0.0146	0.0109
18	0.040	....	......	......	10,000	15,000	20,000	30,000	40,000	....	.....	......	0.0491	0.0328	0.0246	0.0164	0.0123
19	0.036	....	......	......	9,000	13,500	18,000	27,000	36,000	....	.....	......	0.0546	0.0364	0.0272	0.0182	0.0136
20	0.032	....	......	4000	8,000	12,000	16,000	24,000	32,000	....	.....	0.133	0.0614	0.0403	0.0306	0.0204	0.0153
21	0.0285	....	......	3560	7,120	10,680	14,250	21,360	28,500	....	.....	0.149	0.0690	0.0460	0.0342	0.0230	0.0172
22	0.0253	....	......	3160	6,320	9,490	12,650	18,980	25,300	....	.....	0.168	0.0777	0.0518	0.0388	0.0259	0.0194
23	0.0223	....	......	2830	5,660	8,470	11,300	16,940	22,600	....	.....	0.187	0.0868	0.0580	0.0434	0.0290	0.0217
24	0.0201	....	......	2510	5,020	7,520	10,050	15,040	20,100	....	.....	0.211	0.0978	0.0654	0.0488	0.0327	0.0244
25	0.0179	....	......	2240	4,480	6,710	8,950	13,420	17,900	....	.....	0.237	0.109	0.0732	0.0548	0.0366	0.0274
26	0.0159	....	995	1990	3,980	5,960	7,950	11,920	15,900	....	0.533	0.266	0.123	0.0824	0.0618	0.0412	0.0309
27	0.0142	....	890	1780	3,560	5,320	7,100	10,640	14,200	....	0.596	0.298	0.138	0.0924	0.0690	0.0462	0.0345
28	0.0126	....	790	1580	3,160	4,720	6,300	9,440	12,600	....	0.671	0.335	0.155	0.104	0.0778	0.0520	0.0389
29	0.0113	....	705	1410	2,820	4,240	5,650	8,480	11,300	....	0.752	0.376	0.174	0.117	0.0868	0.0586	0.0434
30	0.0100	312	625	1250	2,500	3,750	5,000	7,500	10,000	1.70	0.850	0.424	0.196	0.131	0.0982	0.0655	0.0491

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† The cross-section, for widths up to and including ⅛″, is not a true rectangle by about 8%, and the figures in columns marked † are 8% above the theoretical values. This approximation is correct for average sizes, but the narrower the ribbon in proportion to its thickness, the greater is the departure of the tabular rules from the true resistance.

If ribbon is to be used instead of wire, required comparison number of ribbon $=(279/297)\times 5560=5210$.

From Table XVII, it is seen that No. 15 gage ribbon, $\frac{1}{2}$ in. wide, would be suitable.

From Table XIX, its resistance when cold $=0.0172$ ohm/ft.

This is increased 10 per cent when the resistor is hot, giving 0.0189 ohm.

$$\frac{0.54 \text{ ohm required}}{0.0189}=28.6 \text{ ft. required per section,}$$

or

$$2\times 28.6=57.2 \text{ ft. required for one side-wall.}$$

(*c*) Four sections in parallel:

$$410/4=103 \text{ amperes, each section;}$$

$$4\times 0.27=1.08 \text{ ohms resistance of each.}$$

Tabular carrying capacity required at 1800° F. $=103/(73\frac{1}{2}\%)$ $=140$ amperes.

The nearest size (Table XVI) of round wire is No. 6 gage, which has a hot resistance of $1.10\times 0.0242=0.0266$ ohm per ft.

$1.08/0.0266=40.6$ ft. each section, or 162 ft. total.

If ribbon is to be used, the comparison number is 2700; either No. 22 ga. ribbon $\frac{3}{8}$ in. wide or No. 24 ga. ribbon $\frac{1}{2}$ in. wide, would be suitable. The latter, which would have more of a margin of safety, has a hot resistance of 0.0537 ohm per ft.

$1.08/0.0537=20$ ft. per section, or 80 ft. of ribbon, total for one side-wall.

(*d*) Eight sections in parallel:

$$410/8=51 \text{ amperes each;}$$

$$8\times 0.27=2.16 \text{ ohms each section.}$$

Required tabular value for carrying capacity at 1800° F. $=51/(73\frac{1}{2}\%)=69.4$ amperes.

From Table XVI, the nearest size is No. 10 ga., of hot resistance 0.0676 ohm per ft.

$2.16/0.0676=32$ ft. per section, or 256 ft. per side.

If ribbon is used, comparison number is 1345; either No. 22 ga. ribbon $\frac{3}{16}$ in. wide, or No. 27 ga. $\frac{1}{4}$ in. wide would be suitable. Using the latter, with hot resistance 0.152 ohm per ft., the length required is:

$2.16/0.152=14.2$ ft. per section, or 115 ft. in all, per side.

Selection from the above and other possible combinations depends upon (*a*) ease of arrangement and of making connections, and (*b*) durability. The size of ribbon should bear some proportion to the size of the furnace. For the cases figured above, if the wires or ribbons are uniformly spaced, their distance apart would be about as follows:

Number of sections	1	2	4	8	
Round wire	...	$1\frac{3}{4}$	$1\frac{1}{8}$	$\frac{3}{4}$	Distance, inches,
Ribbon	$5\frac{5}{8}$	$3\frac{1}{8}$	$2\frac{1}{4}$	$1\frac{5}{8}$	center to center.

They should, however, be spaced closer together near the doors of the furnace and in similar places, where heat abstraction tends to produce cold spots. With this consideration in mind, it is clear that the 8-section and even the 4-section arrangements would require entirely too close spacing, with narrow and fragile supporting plugs, and that the 2-section arrangement is the most desirable of those figured.

It is especially desirable in the case of ribbon resistors to use a rather thick section. If thin ribbons are used, any spot which is thinner than the average, or which cannot dissipate its heat readily (as for instance the part of the ribbon shielded by the supporting pin), becomes hotter than the other parts, because heating is proportional to the resistance and because temperature is inversely proportional to heat abstraction. The hot spot oxidizes more rapidly than the colder parts; the effective section is thereby reduced, its resistance is further increased, and the temperature is raised still higher; the action is cumulative, finally resulting in the burning out of the ribbon at that spot. Such burning out has actually occurred in many cases. In the thicker ribbons, either an initial variation in thickness or a decrease due to formation of a film of oxide would be much less serious, in proportion, than in the thin ribbons.

If the resistor is to be placed behind a solid muffle, a rate of heat emission of 3 kw. per square foot of wall surface doubtless would result in a higher temperature of the resistor than it can safely withstand when subjected to oxidation. The safe rate of emission depends on the furnace temperature and on the thickness and conductivity of the muffle. To complete the example, it will be assumed that the muffle is fireclay, and is $\frac{3}{16}$ in. thick. The safe rate of heat emission is found in the following manner:

First, it is necessary to know what the heat emission from the resistor is, in terms of the emission from a solid wall maintained at the resistor temperature. The radiation from 1 sq. ft. of wall surface at 2000° F. to surfaces at 1600° F., as calculated from the equation on page 146, would be:

$$0.15\times\left[\left(\frac{2000+460}{100}\right)^4-\left(\frac{1600+460}{100}\right)^4\right]=28{,}000\text{ B.t.u./hr.}$$

But the emission of heat corresponding to 3 kw. per square foot is:

$$3\times 3417 \text{ B.t.u./kw.-hr.} = 10{,}250 \text{ B.t.u./hr.}$$

The radiation from the resistors and the wall back of them, Fig. 138, is, therefore, $\frac{10{,}250}{28{,}000}=0.366$ of the radiation from a solid wall at the resistor temperature. This factor appears in the following equation as 36.6 per cent:

Since, for steady conditions, heat transmitted to muffle equals heat radiated from muffle.

$$36.6 \text{ per cent}\times 0.15\times\left[\left(\frac{2000+460}{100}\right)^4-\left(\frac{T_1+460}{100}\right)^4\right]$$

$$=10/(\tfrac{3}{16}) \text{ B.t.u.}\times\text{inch/sq. ft., hr., °F.}\times(T_1-T_2)$$

$$=0.15\times\left[\left(\frac{T_2+460}{100}\right)^4-\left(\frac{1600+460}{100}\right)^4\right]$$

from which

$$T_1=1807°\text{ F.},$$

and

$$T_2=1701°\text{ F.}$$

The relative heat emission, compared with that of the unmuffled resistor, is

$$\frac{0.15\times\left[\left(\frac{1701+460}{100}\right)^4-\left(\frac{1600+460}{100}\right)^4\right]}{0.366\times 0.15\times\left[\left(\frac{2000+460}{100}\right)^4-\left(\frac{1600+460}{100}\right)^4\right]}=0.56,$$

or slightly more than one-half; and the capacity of the muffled resistor is:

56 per cent $\times$ 3 kw. $=1.7$ kw. per square foot of wall surface, for a 1600° furnace. For lower furnace temperatures, the capacity is higher for both muffled and unmuffled resistors.

Considering two sections per wall, the current per section is:

$$\sqrt{0.56}\times 205=154 \text{ amperes.} \quad \text{(See } (b)\text{, above.)}$$

The heat emission is also reduced, however, and the tabular value required is

$$\frac{\sqrt{0.56}\times 205}{\sqrt{0.56}\times\sqrt{0.54}}=279 \text{ amperes, as for the unmuffled resistor.}$$

The comparison number is also the same as before, and the size required is No. 15 ga. ribbon, $\frac{1}{2}$ in. wide.

The resistance required is $1/0.56=1.79$ times that given under (*b*) and the length is $1.79\times 28.6=51$ ft. per section or 102 ft. in all. The ribbons, if evenly spaced, would be $1\frac{11}{16}$ in. apart.

With the muffled resistor, then, the heating capacity per square foot of wall is only about half as great as with an exposed resistor, the size of wire or ribbon is the same, but the spacing is about twice as close. On account of the poor thermal conductivity of fireclay it is not used as material for muffles in electrically heated furnaces. Instead, alundum or carborundum is used and the walls are made twice as thick as the wall in the example.

All of the wire and ribbon sizes figured in these examples are based on 2000° F., operating temperature; and while good-quality chromium-nickel alloys can withstand even higher temperatures without suffering excessively rapid deterioration, the margin of safety is not great. For that reason it is usually preferable, where the amount of space available for the resistors permits, to figure the latter on the basis of 100° to 200° F. lower operating temperature which results in a much greater margin of safety and longer life of the resistors

CHAPTER III

CONTROL OF FURNACE TEMPERATURE

The Problem.—The title, "Control of Furnace Temperature," is somewhat misleading, because it is the temperature of the *charge*, rather than the temperature of the *furnace*, which needs control. In spite of this serious inaccuracy, the title has been retained, in its present form, because of its general acceptance by furnace engineers.

Depending upon the nature of the heating process, the aim is either to:

(*a*) Bring the charge up to a given temperature, and keep the latter constant with regard to time, or

(*b*) vary the temperature of the charge according to a given cycle of time.

In either case it is desired to keep the temperature quite uniform throughout the charge or stock, that is, with regard to space or location in the furnace. The reasons for the desirability of reaching a given temperature in the charge and for not exceeding it are quite simple. For each given process and material there is needed a certain minimum temperature, which must be attained if the process is to be successful. A temperature much in excess of the minimum not only is a waste of heat, but often produces undesirable results, such as scaling, melting, chemical changes, cracking, etc.

The Means for Maintaining a Constant Temperature.—Temperature is determined by a balance between heat inflow and heat outflow. If more heat flows into a body than passes out of it, the temperature rises. Exceptions to this rule are caused by latent heat of fusion, vaporization, or molecular rearrangement.

Temperature is increased by turning on more heat; it is lowered by turning off heat. An increased supply of electrical energy or of fuel and air (up to certain limits) results in higher

temperature, while a decreased supply causes a drop in temperature.

Space Uniformity of Temperature.—From the foregoing statement it follows that the ideal way of adding heat to the charge consists in imparting heat to each molecule, because, by that method, every particle of the stock would be heated uniformly. The method in which the heating stock is used as a resistor for electrical energy comes closest to this ideal. If an electrical current is passed through a steel bar of constant cross-section the bar is heated rather uniformly. In most cases this procedure is not applicable, and heat is imparted to the surface of the charge from a hotter body, such as a resistor, a flame, heated brickwork, or heated gases. Flow of heat presupposes a temperature potential, temperature difference, or heat-motive-force, and lack of uniformity of temperature inside the charge. As long as the difference between flame temperature (combustion temperature) and final or desired temperature of stock is not too great the problem is comparatively simple. As the final temperature is approached, heat flow from the hot body (resistor, products of combustion) to the charge becomes slower, on account of the diminished temperature potential, and there is a chance for temperature equalization in the charge, particularly if its material has high thermal conductivity.

Difficulties arise if the temperature difference between heating element (resistor, products of combustion) and final temperature of the charge is considerable. This condition occurs if the stock is to be heated to temperatures such as 600° F., 1000° F., 1200° F., or 1400° F. If the material which is to be heated to 1000° F. were exposed to a bright flame having a temperature between 2500° and 2800° F., the outside would be much overheated long before the inside had reached the desired temperature. The danger of local overheating is increased if pieces to be heated are placed too close to inlet ports or resistors.

Several means of reducing the temperature potential are in use. They are enumerated in the following classification:

(*a*) Turning heat on and off at regular intervals of short duration.

(*b*) Placing a small source of high-temperature heat at a distance from the surface of the charge.

(*c*) Interposing perforated walls (heat ports) between the source of heat and the charge.
(*d*) Placing the charge or the flame in a muffle.
(*e*) Causing circulation of furnace gases, thereby distributing the heat of a small flame through a large amount of furnace gases.
(*f*) Use of "lazy" flame or of low-temperature resistors.

Regardless of the final temperature of the charge, the following means is used for securing space uniformity of temperature:

(*g*) Addition of heat from all sides (by enveloping charge in heat, having hot gases or resistors on all sides.)

These means will now be discussed in detail.

(*a*) *Turning heat on and off at regular intervals of short duration.*

This method is very effective, but is not suitable for manual control. It is too expensive to have a man at every furnace, busy every minute with the operation of the fires or resistors. The method has been very successfully developed for automatic control of furnace temperature and will be found described on pages 167 to 186 of the present chapter.

(*b*) *Placing a source of high-temperature heat at a distance from the charge.*

This method is seldom employed by itself, but it is quite common in conjunction with methods (*c*), (*d*), and (*e*). Its general application can be seen from Fig. 139. The principle is simple, and can be illustrated by an analogy. If an electric light is placed low, at a short distance above a table, illumination of the latter will be far from uniform, and will be very intense over a limited area. If the light is placed at a considerable height, illumination will be less intense and more uniform. This point is well illustrated by the difficulties encountered with batch-type electric furnaces having resistors on the sidewalls only. Although the reasons are obvious, it took heat treaters a long time to learn why the products frequently varied in such furnaces in spite of automatic temperature control.

(*c*) *Interposing perforated walls (heat ports) between the source of heat and the charge.*

In principle, this method is similar to method (*b*), because it exposes the charge to radiation from small bright spots located at some distance from the charge; in addition, there is usually some

dilution of the hot products of combustion (principle (*e*)). This method is very common. It was illustrated in Figs. 10, 16, 47, and 160 of Volume I of "Industrial Furnaces." It is further illustrated in Fig. 140 of the present volume. While the method of using heat ports is effective in reducing heat transmission to the charge, it must be used with care. Heat ports above the charge, as in overfired furnaces, do not produce uniform heating; the bottom of the charge remains cold (see Volume I, page 303). Moreover, heat ports introduce another disadvantage: the com-

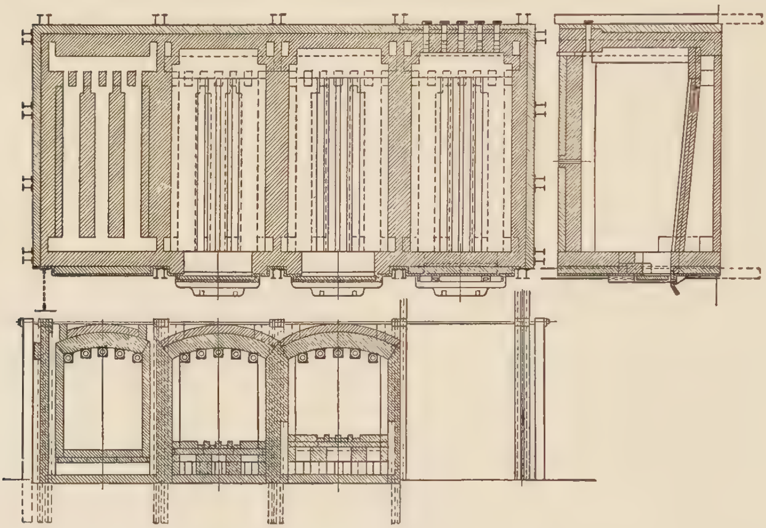

FIG. 139.—Gas-fired furnace for heating sheets. Uniform temperature distribution in heating chamber is obtained by locating many sources of radiation at a distance from the charge.

bustion chamber is, as a rule, very hot, and great losses are unavoidable because the refractory material of that chamber must be protected against overheating. This protection is secured by making the walls thin and exposing the outside to the cool atmosphere.

If the products of combustion pass along an extended combustion chamber the heat ports are made small at the hot spot of the flame, and are made larger and longer as the products of combustion cool off in their travel. It will be noticed in Fig. 140 that the arrangement of heat ports contradicts this rule. In the

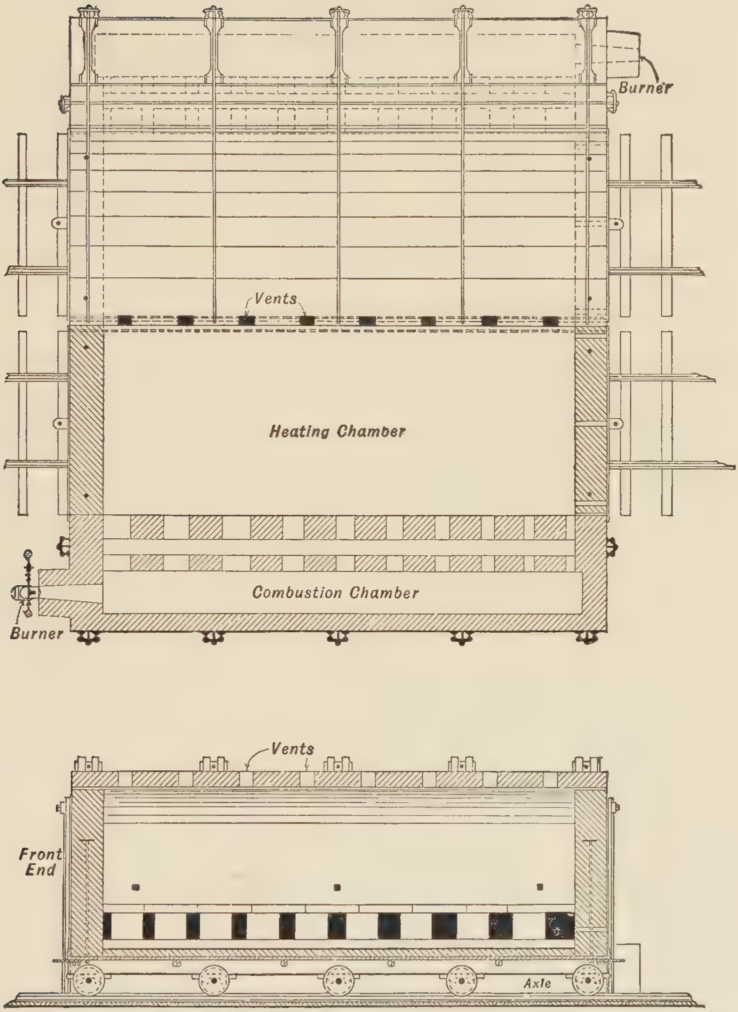

FIG. 140.—Indirect-fired car-type annealing furnace.

Note the heat ports for equalizing temperatures in heating chambers. These ports are made smaller toward the ends farthest from the burners, for the purpose of equalizing the flow of gases. Burners are at opposite ends on opposite sides of furnace.

furnace shown in that illustration, a circumstance, not usually encountered in long combustion chambers, enters. The kinetic energy of the products of combustion is so high that it would send most of the heat to the far end, and would suck gas from the heating chamber into the near end of the combustion chamber, if the ports had not been made very small at the far end. In

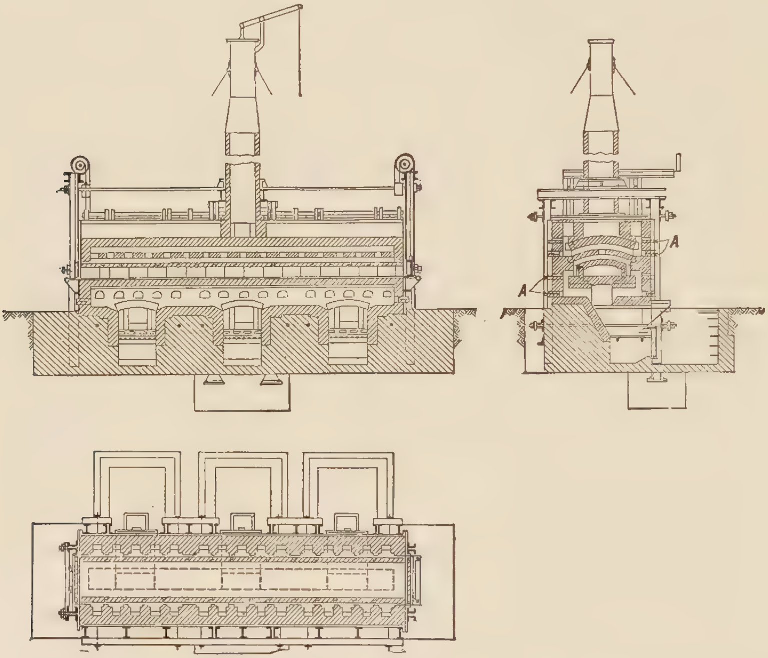

FIG. 141.—Muffle furnace with flame outside muffle.

Note adjustable bricks "A" for regulating combustion to maintain uniform temperature on the outside of the muffle.

order to guard against unforeseen contigencies it is frequently desirable to provide adjustable openings, for instance, by movable tiles, which are moved until the desired temperature distribution has been reached.

(*d*) *Placing the charge or the products of combustion in a muffle.*

Muffles retard heat transfer (see Volume I, pages 42 and 43); for that reason they allow temperature equalization in the charge. The thicker the muffle, the better the temperature equalization in the charge and the lower the rate of heat transfer; on the other

hand, the danger of cracking the muffle is very great. (See Volume 1, page 249.) If the charge is placed in a muffle, the heat which is lost by the surrounding products of combustion is considerable, because a large part of the heat goes through the outside walls. If combustion takes place in a muffle, and the charge surrounds it, heat losses can be reduced.

A muffle furnace is illustrated in Fig. 141. It will be noticed that adjustable bricks are used for admitting air and regulating combustion. This method tends to maintain a uniform temperature on the outside of the muffle and is virtually an application of

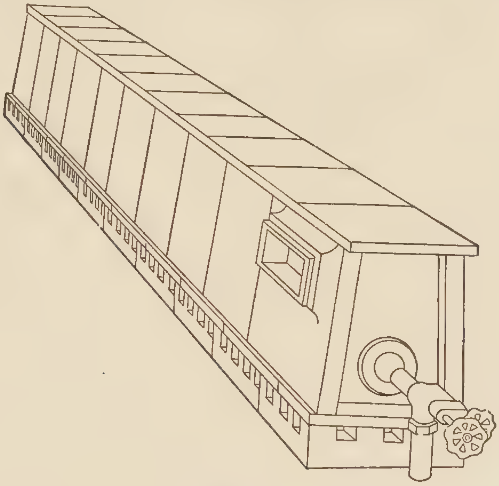

FIG. 142.—Muffle with flame inside.

method (*f*) (lazy flame). Placing the flame in a muffle is illustrated in Fig. 142. This particular muffle is made of a silicon-carbide mixture, which allows fairly high rates of heat transfer, and which maintains high mechanical strength even when it becomes quite hot.

(*e*) *Causing circulation of furnace gases, thereby distributing the heat of a small flame through a large weight of furnace gases.*

This method is discussed in Volume I, pages 294 to 308. It is excellent, and deserves to be used more extensively. Briefly stated, it consists in using the jet action of a small high-velocity flame for the purpose of inducing furnace gases and circulating them around and through the charge. In furnaces carrying a low

temperature (frequently called ovens) circulation may be provided by a fan which is driven by a shaft projecting through the oven wall. By a rapid circulation of the furnace atmosphere all temperature differences can practically be eliminated.

(*f*) *Use of a lazy flame or of low-temperature resistors.*

Comparatively low temperatures, lying just above the kindling temperature of the fuel, can be obtained by letting air and fuel enter the furnace chamber in parallel streams with approximately equal velocities. Combustion then takes place slowly, by diffusion, and heat is produced through the whole length of the flame travel. Temperatures low enough for annealing of steel have been obtained by this method with a rich fuel such as powdered coal.

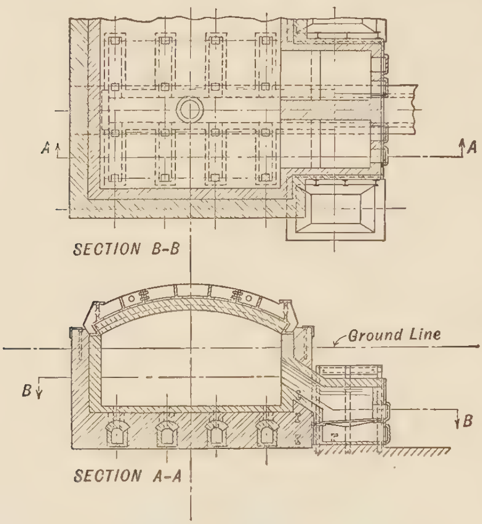

FIG. 143.—Annealing pit.

Note direction of gas inlet and location of outlet ports for obtaining circulation of gases.

An annealing pit which combines methods (*e*) and (*f*) is illustrated in Fig. 143. Circulation is caused by the direction of flow of the gases and by the well-chosen location of the outlet ports in the hearth. A lazy flame is obtained by incomplete combustion on the grate and by infiltration of air through the cracks between the sections of the cover. It may be remarked that the purpose of this scheme is frustrated if pieces are piled in front of the inlet port.

If electric resistors are used it is quite easy to regulate the ratio between voltage, length, and cross-section of resistor in such a manner that a low temperature of resistor is maintained. In this respect, electric heat is very convenient.

(*g*) *Addition of heat from all sides.*

This method is also discussed in Volume I. Properly designed

under-fired furnaces and electrically heated furnaces with heating elements on all sides (including the hearth) are examples of this type. Blocking up of the charge above the hearth or suspension from the roof is intended to accomplish the same object.

Temperature Regulation with Regard to Time.—When it is a question of maintaining a temperature constant with regard to time one finds too often that the eye of the heater is the only pyrometer and his hand the regulating device. If hand control is used, pressure regulators (reducing valves) on fuel and air lines help to maintain constant conditions. Increasing costs of labor and increasing demands for uniformity of heating have resulted in the development of automatic control of furnace temperature. A careful examination of the literature indicates that automatic control of furnace temperature originated in the United States and was applied to gas-heated furnaces as early as 1908. The original device (for description of which see page 180) while quite successful and still marketed to-day, was not introduced rapidly on a large scale, probably because furnace temperature can be kept reasonably constant with gas firing even if no automatic-control mechanism is used, and also because the good effects of the new device were not appreciated by the trade. Matters are quite different with electrically heated furnaces of the resistor type. In that type of furnace, hand control of temperature is almost out of the question, and, where it is introduced, becomes extremely wasteful, because hand control means the adjusting of an external resistance in which heat is generated without reaching the furnace.[1] Since, in this manner, external resistances result in wasting a great deal of energy, electrical engineers were compelled to devise some other method of adjusting the supply of energy. A method which operates without an external resistance and is, for that reason, free from losses consists in alternately turning on and turning off the supply of electrical energy. It is impracticable to do this work by hand, since it has to be done very frequently and at regular intervals. The problem was solved by a double relay, controlled by a thermometer or a thermo-electric couple (for description see pages 168 and following).

Automatic temperature control, which is a positive necessity

[1]Adjustment of transformer ratio by switching affords a method of hand regulation without loss of energy, but the adjustment is seldom close enough. The method is used only occasionally.

in electrically heated furnaces, was soon recognized to be one of the advantages of electrical heating, and electrically heated furnaces were installed in large numbers solely for the reason that they allowed perfectly automatic and reliable temperature control. Intensive advertising increased the popularity of this type of furnace. Figuratively speaking, the builders of gas and oil fired furnaces were left out in the cold. The incentive for inventing and perfecting automatic temperature-controlling equipment for such furnaces was very great and was promptly met. In contradistinction to the early form of apparatus, which used slightly compressed (or blast) air, the latter devices use electrical energy as motive power.

The basis of all of the various devices now on the market for automatically controlling furnace temperatures is a temperature-measuring device, the construction of which depends upon the type of furnace in which it is to be used. For low-temperature work (below 800° F.) a gas or vapor thermometer or a thermostat is used. In electrically heated furnaces for heat treating or drawing (below 1500° F.) a bare couple of iron and constantan (a nickel-copper alloy) is very suitable. At a temperature of 1400° to 1500° F. bare couples last several weeks if made of No. 8-gage wire. Frequently, the constantan wire is placed inside of an iron tube and is welded to the tube at its hot end, but is otherwise insulated from it. In furnaces of the combustion type the couple is, as a rule, located in a protecting tube, because the iron part of the couple is oxidized too quickly if exposed to the hot gases. For higher temperatures (up to 1900° F.) nickel-chromium alloys are in common use. Above that temperature, couples made of platinum and platinum-rhodium must be used.

The electromotive force of a thermocouple, or the expansive force of a gas in a small bulb, is much too feeble to adjust a valve or to throw a switch. It is made useful for this purpose by letting the position of the needle of a thermometer, galvanometer, or potentiometer affect the direction of an electric current. Several methods are in use. One consists in letting the indicating needle of the thermometer, galvanometer, or potentiometer make electric contacts at adjustable " high " or " low " positions (see Fig. 144). Another method is identical with the one employed in the depressor bar instruments. At regular intervals a clockwork or an electric motor depresses the needle (1) (Fig. 145), that is to say, moves it

at right angles to its direction of swing. If the pyrometer reads low, contact is made and a weak current is made to flow through one relay. If the pyrometer reads high, another contact is made, and a current is made to flow through another relay. The current, in passing through the relay, releases a larger force, which may be electrical, hydraulic, or mechanical, and which controls the supply of electrical energy or of fuel and air to the furnace. A third method (not illustrated) uses a thermocouple for the pointer of the pyrometer, and places an electrically heated resistance at that temperature indication at which the temperature control is to act. When the pointer approaches the heater, a current flows through the pyrometer pointer and operates a relay, which, in turn, acts upon the temperature control.

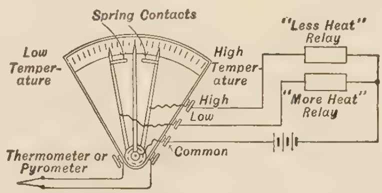

FIG. 144.— Diagram of temperature regulator, contact type.

A brief, non-detailed description of some of the equipment, together with a discussion of some of the precautions which must be observed if good results are wanted, will illustrate the underlying principles.

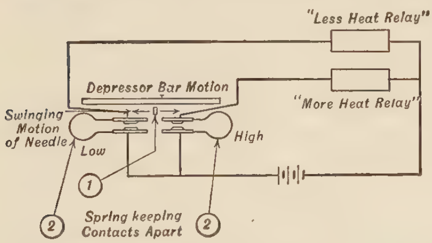

FIG. 145.—Diagram of temperature regulator, depressor bar type.

Before entering into this discussion it is desirable to answer a fundamental question, namely: To what extent can the temperature of the heating stock be controlled? At first thought it would appear that perfect control could be attained by placing the temperature-measuring instrument at that point of the stock which takes longest to come up to temperature. In regular operation, however, it is quite impossible to bury the thermometer or thermocouple anywhere in the charge, because if this were done the instrument would most certainly be injured. It must, therefore, be placed somewhere else in the furnace. If the instrument projects very far from the roof or through the sidewalls it is like-

wise exposed to injury. For these reasons it must be placed in a protected position, projecting very slightly, if at all, from the wall in which it is located. If the thermometer or thermocouple is bare it indicates the temperature of the objects immediately around it in the furnace; but if it is inside of a protecting tube it most certainly can measure nothing else but the temperature inside the tube. Obviously, there will be a considerable difference between the temperatures of the charge and of the thermometer or couple during some phase of the heating process. There is no theoretically correct way of telling the temperature difference

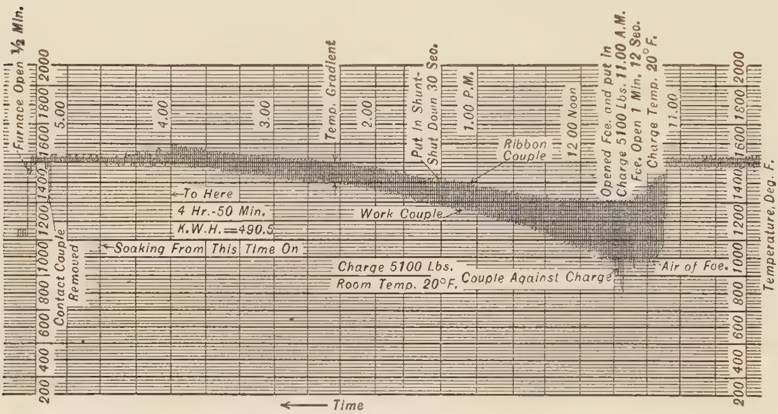

FIG. 146.—Time-temperature chart of furnace with automatic control. Upper boundary of curve represents temperature of furnace near resistor ribbon; lower boundary represents, first, temperature of air in furnace, then temperature of charge after it is put in.

between the measuring instrument and the most remote part of the charge, but the following method allows a sufficiently close approximation for practical purposes: An experimental run is made, during which the variation of the temperature of the controlling device is observed simultaneously with the temperature of one or more points in the charge. At first these various temperatures will be far apart, but, as time passes, they will approach each other, as indicated in Fig. 146, which shows the readings of two pyrometers. The time is observed which must elapse on the almost horizontal branch of the upper curve before the temperature of the test couple at the slowest point of the charge has come up to the required value. From this test data are secured

for future similar charges in the furnace. If this or a similar precaution is used, the temperature of the stock can indeed be controlled very closely, provided that the charge is piled in the same manner as before. It should be understood that the mere presence of a temperature-controlling device (or even a good-looking pyrometer chart) is not a guarantee of correct and uniform heating.

In large furnaces a two-point instrument which records and controls the temperature of the furnace and of the charge is used regularly. From this viewpoint automatic control is not a device for keeping temperature constant, but for bringing all parts of the charge up to temperature without overheating any part of it.

As previously mentioned, a detailed discussion of the various thermometers and thermocouples used in temperature control does not belong in a book on industrial furnaces. It is, however, appropriate to show a few types of controlling mechanisms.

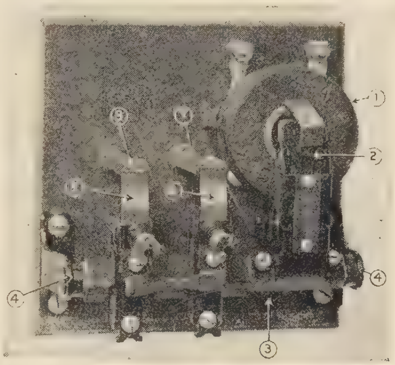

FIG. 147.—Electric relay for temperature control.

(1) Magnet coil, (2) armature, (3) shaft, (4) bearings, (5) and (6) contact fingers, (7) contact post, (8) spring contact post.

A typical form of relay is shown in Fig. 147. A relay is, in effect, a trigger device, by which a small amount of electrical energy controls a much larger amount of energy. In Fig. 147 (1) is the coil containing a large number of turns of wire, through which the feeble current, for instance, that from the contactor of the galvanometer, flows, exerting attractive force on the armature (2), which moves toward the coil, turning the shaft (3) held in bearings (4). The motion of the shaft causes contact of fingers (5) and (6) with posts (7) and (8), thereby completing the circuit for a much heavier current, such as the main heating current for the electric furnace. When the feeble current stops flowing in coil (1) the attractive force ceases, and the spring contact (8) moves finger (5) out, turning the shaft and breaking contact of finger (6) with (7).

For controlling electric furnaces two relays are usually provided in series, as indicated in the wiring diagram, Fig. 148. In this arrangement the feeble current from the control instrument excites the coil of control relay (7), closing the circuit through the main relay (8). The strong current through the contacts of the control relay acts as the (relatively) feeble or trigger current of main relay (8), thereby closing the main circuit and permitting the heating current to flow through the resistors of the furnace.

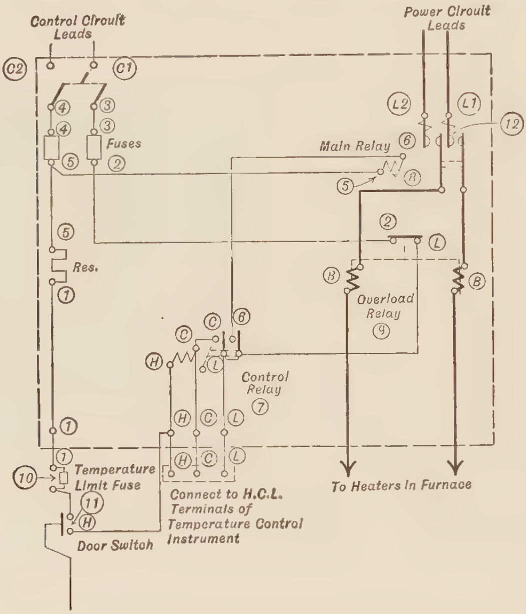

FIG. 148.—Wiring diagram for control of electric furnaces.

Note the control relay operated by pyrometer current, actuating main relay in power circuit; also temperature-limit fuse and door switch.

A short explanation may make the wiring diagram of Fig. 148 clearer. C_1 and C_2 are the leads from the source of current used to actuate the relays. These connect through (5), (1), (2), temperature limit fuse (10) and door switch (11), to terminals H (high), C (common), and L (low), which are connected to the temperature-control instrument. When the furnace temperature drops and the galvanometer makes contact to raise the temperature, the control current flows through coil HC of relay (7), closing contacts C and (6). This completes the circuit through

coil (5–6) of main relay (8), the action of which closes the main circuit supplying current to the heating coils in the furnace.

An overload relay (9) is also provided. If, owing to a short-circuit or any other cause, the current flowing to the furnace through coils B becomes excessive, the attraction of the armature by these coils breaks the circuit to the control relay at 2–L, thus causing main relay (8) to break the main circuit.

Other protective features are provided by temperature limit fuse (10) and door switch (11). If the temperature control should fail to operate and the temperature should become excessive, the melting of fuse (10), which is located in the furnace, would open the control circuit, whereupon relay (8) would open the main circuit. When the door of the furnace is opened, door switch (11) opens the control circuit, causing the opening of the main circuit and thus protecting the workmen from the danger of electric shock, in case the material which is being charged comes in contact with the heating elements. The construction of relays is, of course, a specialized branch of manufacture; they are standard electrical equipment, and are furnished by firms specializing in electrical apparatus.

Temperature-controlling devices for combustion furnaces are, in many respects, similar to those of electrically heated furnaces. Many of them come as close as possible to the "all or nothing" method of the electrically heated furnace by varying the supply of fuel and air between "all on" and "as little as is required to safely maintain combustion." In other devices the supply of heat fluctuates within narrower limits and the mean position about which the supply oscillates can be adjusted either by hand or else automatically. Motive power is furnished either by a solenoid or by an electric motor.

In all of these types new forms appear from time to time. The apparatus which is described here is chosen only because it is typical; its selection does not imply that it is necessarily the best on the market.

The instrument shown in Fig. 149 consists of a fuel valve and an air valve, both of which are kept open by solenoids against spring force, as long as the power is on. If the latter should go off, the valves are almost closed by the springs. It is, of course, not feasible to close the valves entirely, because of the uncertainty in relighting the flame when the valves are opened again. The

adjustment for minimum fuel and air flow is made in the control valves, by twisting bar-shaped handles which are visible at the extreme right and left of the illustration. The solenoids, which are made large enough to operate the valves even if the line voltage drops 25 per cent, are controlled by a thermocouple and a relay. This type of furnace control can be used for fuels such as oil, or any clean gas.[1]

Among the furnace controls intended for oil fuel there are a few which do not affect the flow of combustion air, but adjust the flow of fuel and of air or steam for atomizing. Such devices control temperature, and produce good-looking pyrometer charts, but cause great variations in furnace atmosphere. By rights all three fluids should be controlled. Very few builders of furnaces or of controlling devices have the courage to manufacture apparatus designed to control oil, combustion air, and atomizing medium.

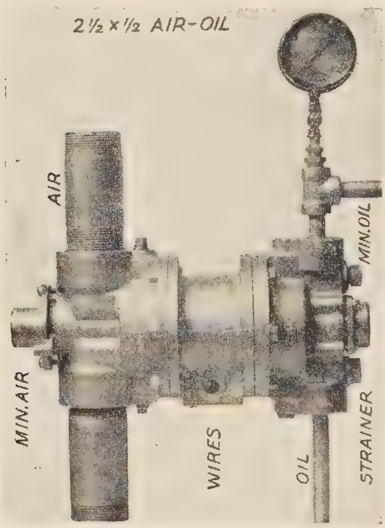

Fig. 149. — Temperature - controlling device for oil-fired furnaces. Oil valve and air valve are operated by a solenoid.

In addition to the equipment shown in Fig. 149 several other makes of solenoid-operated valves for automatic temperature control are offered to the American market, and their number is increasing.[2]

While the "all or nothing" method of energy supply is a positive necessity in electrically heated furnaces it is by no means necessary with fuel-fired furnaces. On the contrary, it is considered by some engineers to be a crude makeshift. They reason that the correct principle in fuel-fired furnaces consists in gradually

[1] For a more detailed description, see *Fuels and Furnaces*, October, 1923, page 437.

[2] A number of these devices were described in *Forging and Heat Treating*, January, 1923.

increasing or decreasing the supply of heat. In the opinion of these engineers, the " all on or all off " method corresponds to the hit-and-miss regulation of an engine, or to a racing governor. In accordance with this view, several temperature-control systems with gradual adjustment have been worked out. In such apparatus the simplicity of the solenoid has to be sacrificed and the complication of using an electric motor must be accepted. Two devices will be described briefly for the purpose of explaining underlying principles.

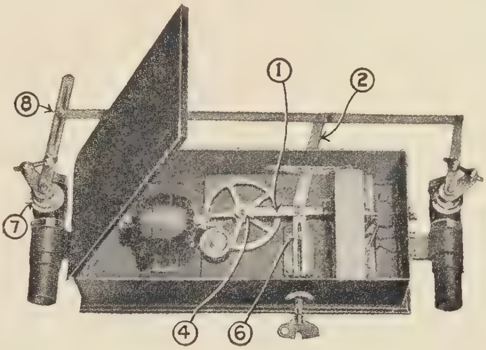

FIG. 150.—Motor-operated controlling device for gas-fired furnaces.

The original and simple form of one of these two instruments is shown in Figs. 150 and 151. After contact has been made by the pyrometer, the gear carrying pin (4) makes one-half of one revolution, thereby throwing connecting rod (1) and rod (2). This motion turns the fuel and the air valves through a certain adjustable range, which can either extend from all to practically nothing (as in the previously described instruments) or can cover very much narrower limits.

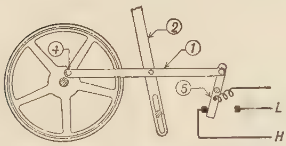

FIG. 151.—Diagram illustrating action of motor-operated controlling device.

For the sake of clearness the principal part of the mechanism has been shown separately in Fig. 151. It will be noticed that, whenever the gear carrying pin (4) has completed one-half of one revolution, the snap switch (5), which is shown at the extreme right-hand end of the illustration, is thrown from one extreme position to the other, thereby getting the circuit ready to be closed by the pyrometer, if it makes contact on the side opposite to the one on which it has just made contact. Then if, for instance, the temperature was too low, and if the pyrometer and motor box had initiated a movement of the mechanism, opening

the valve more than before, the mechanism would assume the position shown in Fig. 151, causing the snap switch to make contact on the "too high" side. In the meantime, no matter how often or how long the pyrometer may make contact on the "too low" side (by means of the depressor bar) no movement can occur in the mechanism, because the switch is set so as to form a circuit in case the pyrometer makes contact on the "too high" side.

The inventor of this mechanism soon realized that the control

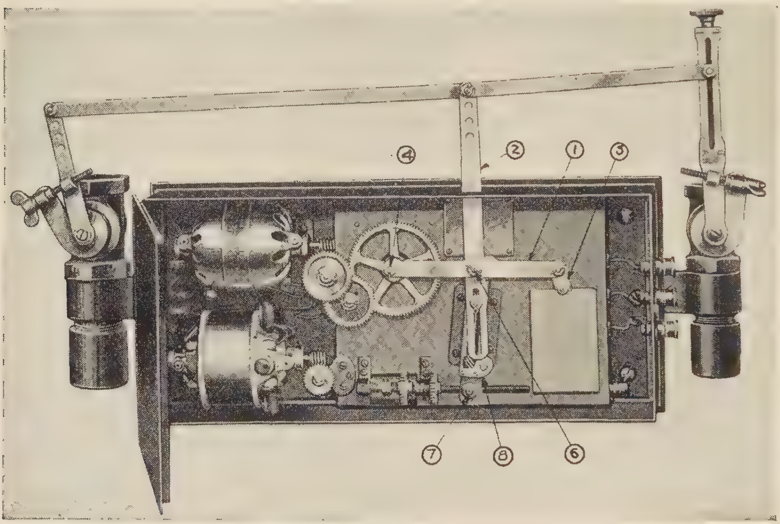

FIG. 152.—Temperature-control apparatus with gradual adjustment of fuel and air quantity.

Note the two-motor control, with adjustable lost-motion arrangement.

furnished by it was patterned rather closely after the "all or nothing" method of the electrically heated furnace; he reasoned that a steadier heat would be secured by letting the above-described mechanism move the valve within comparatively small limits around a controllable position, which could be automatically adjusted by a secondary mechanism.

A device embodying this principle is shown in Fig. 152. In this arrangement the upper motor works exactly as before, adjusting the valve opening up and down around an otherwise determined central position, which is slowly adjusted by the lower

motor to meet the varying requirements of the furnace. If the pyrometer persistently reads either too high or too low, the upper motor is inactive, as explained above, but the lower motor is in the circuit. This motor slowly screws a nut along a threaded shaft between two clutches which are set at an adjustable distance apart, and which are designed to cause lost motion. An adjustable time lag is introduced by this feature. If the pyrometer keeps on pointing in the same direction the lost motion is finally bridged over, and the bottom hinge (7) of the lever (8) lying

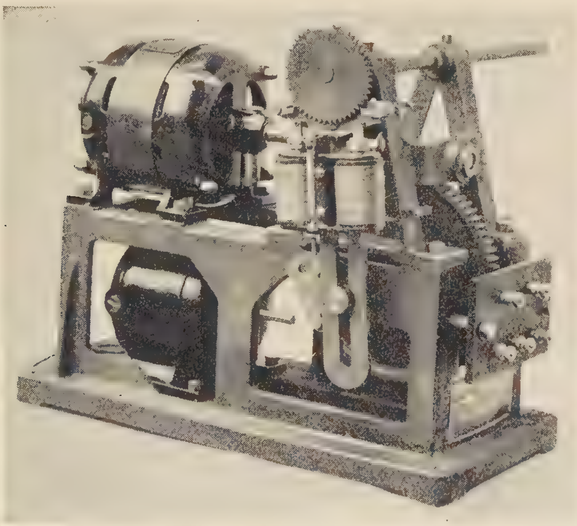

FIG. 153.—Motor-operated control for gradual adjustment of temperature.

behind lever (2) is moved. This movement carries pin (6), which is common to both levers, either to the right or left as may be required, and moves the upper end of lever (2) and with it the control valves, in the proper direction, until a central position is reached, about which the upper motor can perform small oscillations. A limit switch prevents the lower motor's adjusting too far in either direction. The time lag, or lost motion effect, in the action of the lower pyrometer is important, because well-protected pyrometers have a time lag. In consequence, it takes some time for any action of the fuel control to be communicated to the pyrometer. During that time, the lower motor should not

adjust, because it would over-regulate and produce "hunting" (a term well known in the theory of governing). It is, of course, well understood that protected thermocouples regulate with greater temperature fluctuations than bare couples do.

Many adjustments are provided in the mechanism. They should be entrusted only to a person well acquainted with the instrument and with the furnace. After the adjustments have

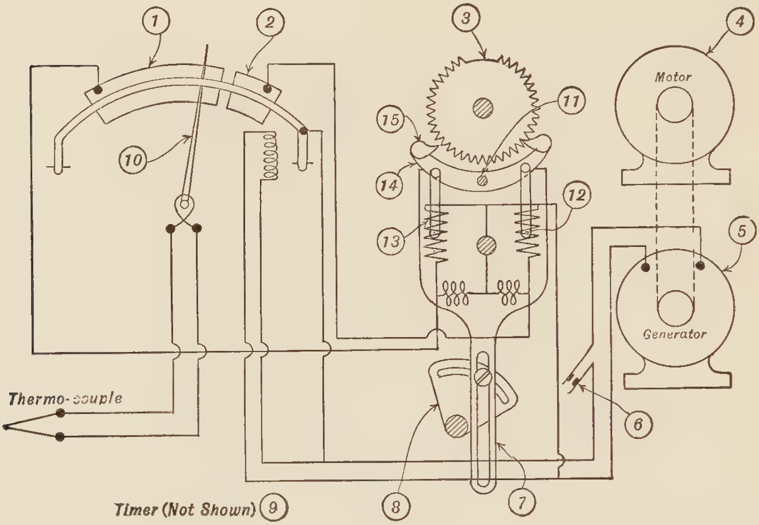

FIG. 154.—Diagrammatic sketch of control device shown in Fig. 153.

been correctly made, the whole outfit can be left to take care of itself.

A wholly different principle is embodied in the automatic regulator shown in Figs. 153 and 154. In this device the principle of keeping a nearly constant supply of heat, adapted to the requirements of the charge and of the furnace, has been kept in view. An external view of the whole controller is shown in Fig. 153, while Fig. 154 is a diagram of the essential parts. A ratchet wheel (3) turns a shaft, to the far end of which are keyed sprocket wheels. The latter carry chains which, by means of other sprockets, open or close fuel and air valves. The rate at which the sprocket is turned is controlled by the pyrometer in conjunction with previously made manual adjustments. A motor (4), by

means of a belt, or a silent chain, drives generator (5). The motor also drives a worm gear, operating a timer (9), located in the rear of Fig. 153, and a crank (8) which oscillates slotted arm (7), carrying two solenoids. Generator (5) generates the correct voltage for energizing either one of the two solenoids. The flow of current to the solenoids is controlled by the depressor bar of pyrometer (10), in conjunction with the previously mentioned timer (9). The depressor bar is actuated by means of a small solenoid which operates whenever the adjustable timer allows

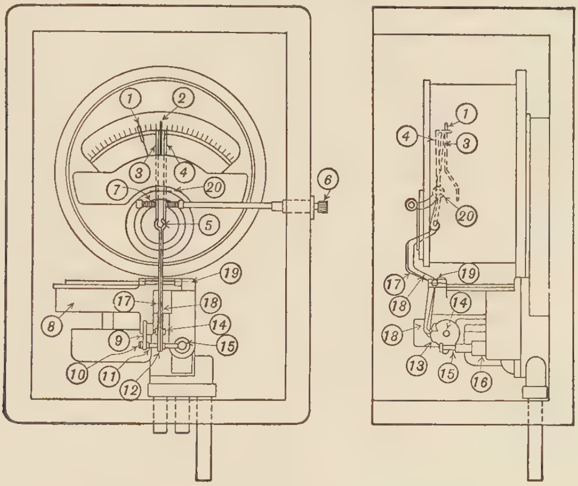

FIG. 155.—Temperature regulator for gas-fired furnaces. It is operated by the pressure of the fan-blast air which is used for combustion.

contact (6) to be closed. The depressing of the bar presses the indicating pointer against contact plate (1) or contact plate (2) or the insulating filler between them. By means of either of the first two contacts, one of the two solenoids (13) and (12) is energized, and yoke (14), which is pivoted at (11), is pulled down to one side or the other, whereby one of the pawls (15) in the ratchet wheel is engaged. Since crank (8) is rotated continuously, the ratchet wheel is, by this action, turned in one direction or the other, and the fuel and air valves are gradually opened or closed. Overwinding is avoided by the blank space in the ratchet wheel.

The last-mentioned device has been described in detail because it is typical of a slow adjustment of combustion with a view to

maintaining a steady heat. Its limitations in this respect are similar to those of the preceding device.

On page 167 mention was made of the original automatic temperature-control device which was applied to gas-heated furnaces. This instrument which (with the exception of a thermocouple) does not make use of electricity, but is operated by mechanical and pneumatic means, is on the market to-day and controls temperature very accurately. For both reasons, namely, that it is of historical interest and that it does the work mainly by mechanical means, a brief description of the principles underlying the operation of the instrument is appropriate. Figure 155 illustrates the instrument, while Fig. 156 is an aggregate of various important details. Gas and air are admitted to the burners through a valve shown in Fig. 157. Adjustable handles (G) and (H) determine the maximum and minimum openings of the valves (A) and (B). The valves are kept in either one or the other of these two positions by air pressure or lack of air pressure under the diaphragm (K). Admission and discharge of air pressure are controlled by a pilot valve (16), Fig. 155 (not shown in detail), and this valve is thrown into admission or discharge position by its stem (15), Figs. 155 and 156. The stem (15) has a lost motion distance a, within which pin (11) of cam (13) can make a given travel without changing the position of the pilot valve (16). Pin (11) carrying roller (10) is oscillated by crank (21) and connecting rod (9) (Fig. 156).

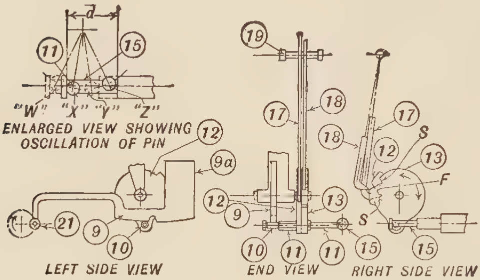

Fig. 156.—Details of cams and valve operation of air pressure-operated controller.

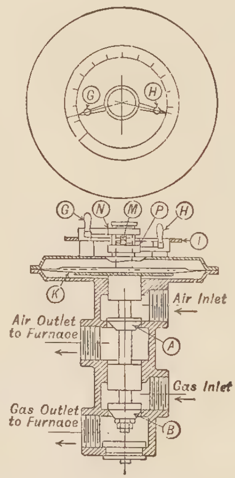

Fig. 157.—Air and gas control valve operated by the device shown in Fig. 155.

Crank (21) is revolved by a little air turbine (which derives its power from the blast air of the furnace) through appropriate speed-reduction gearing. The range through which pin (11) rocks is determined by the furnace temperature in the following manner. Connecting rod (9), Fig. 156, drives pin (11) with roller (10) by means of a notch with sloping sides. As long as there is no serious resistance to motion, driving contact is secured by means of overhanging weight (9*a*) forming part of connecting rod (9). If pin (11) were perfectly free to move it would travel the distance W–Z, Fig. 156, all the time. As soon as the motion of pin (11) meets with an effective obstruction the connecting rod jumps up and rides upon the pin. That obstruction is furnished by hooks on levers (17) and (18) working with cam faces (12) and (13). These faces have different inclinations, as observation of Fig. 156 will show. The outer faces (S) are steep, while the inner faces (F) are not so steep. The outer faces are self-locking; that is to say, when levers (17) and (18) are pressed against the cams, these faces effectively stop further motion of the cams, and pin (11) can travel from X to Y only; it should be noted that, in this short travel, the shallow cam faces (F) move the levers (17) and (18) away from the cams. If these levers are kept away from the cams, pin (11) moves the distance W–Z; if lever (17) is held out and lever (18) presses against the cam, pin (11) moves the distance W–Y; if, on the other hand, lever (18) is held out, while (17) is allowed to make contact, pin (11) moves through the range X–Z. Holding one or the other lever away from the cam changes the travel of pin (11), and thereby adjusts the position of the pilot valve.

The movement of the levers is controlled by the pyrometer needle as illustrated by Fig. 155. The levers (17) and (18) are pivoted at (19) and are joined to rocking arms (3) and (4) which are pivoted at (20). In consequence of the double pivoting, the bottom end of (17) [or (18)] goes in when the top end of (3) [or (4)] goes in. The numeral (1) denotes the pointer of a galvanometer which is actuated by the thermocouple in the furnace, and which indicates furnace temperature. An auxiliary pointer (2) lying farther away from the scale than (1) indicates the desired temperature. On either side of (2) are the above-mentioned rocking arms (3) and (4). The angular position of the system (2) (3) (4) can be adjusted about center (5) by turning

knob (6) and threaded rod (7), whereby pointer (2) is set at the desired temperature. When the furnace temperature is correct the indicating pointer (1) coincides with the position of pointer (2) and lies between arms (3) and (4), which are alternately moving in and out (at right angles to the plane of the scale), on either side of pointer (1). When the indicator pointer needle is on the left of arms (3) and (4) the right arm (4) oscillates in and out of scale slot, while the left arm (3) is idle, and *vice versa* when the needle is on the right of arms (3) and (4), the left arm (3) oscillates in and out of scale slot and the right arm (4) is idle. In the idle position the arms (3) and (4) are raised far enough above the scale to avoid confining the indicator pointer, thus leaving it absolutely responsive to the temperature of the furnace. As mentioned above, the motion of either arm toward the scale corresponds to the entering of the end of lever (17) or (18) into the notch in its corresponding cam.

If pointer (1) departs from the position of pointer (2) it gets into the way of one of the oscillating arms and stops its oscillation. The corresponding follower hook, working in conjunction with cams (12) or (13), is kept away from the cam, and the latter [including pin (11)], not being stopped by the hook, can complete its stroke, and can throw stem (15), and with it pilot valve (16).

In practice, the instrument " hunts," just like other temperature-control instruments. In other words, the temperature is either slightly too high or slightly too low. In the former case, gas and air valves are open too wide, and in the latter case they are not open wide enough. By speeding up the turbine the operation of the instrument can be quickened.

The instrument which has been described in detail operates very successfully. From the rather long description it is quite evident that a purely mechanical temperature control must necessarily be complicated, and that important simplifications can be effected by electromagnetic means.

In furnaces with several burners the number of burners which must be controlled depends upon conditions in the furnace. In a continuous furnace with constant rate of feeding it may not be necessary to control more than one or two burners, but in " in and out " furnaces all burners must be controlled. Figure 158 shows an installation in which this is effected.

Occasionally it is required to control furnace temperature

over a comparatively long distance. Such a condition arises, for instance, in a long tunnel kiln furnace. The average temperature over a comparatively long distance has been controlled successfully by locating thermocouples some distance apart in the furnace and also on opposite sides of the furnace. All of these thermocouples are connected in series. In this manner six thermocouples have in one case been connected in series, with the result that a very much larger electromotive force was obtained than could be obtained with one couple. The galvanometer or potentiometer must, of course, be arranged to take care of this increased electromotive force. While the arrangement in question has proved to be very successful, it requires increased attention,

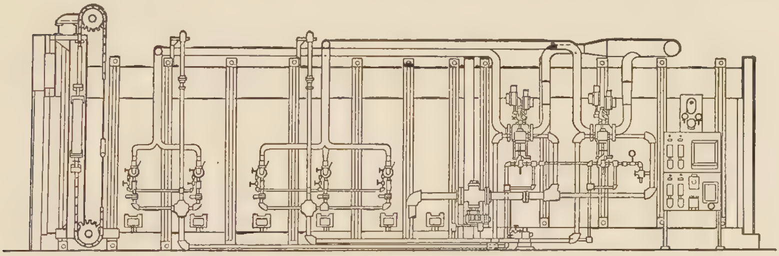

FIG. 158.—Arrangement for controlling a number of burners from one regulating instrument.

inasmuch as the danger of interruption of automatic temperature control due to burning out of thermocouples is multiplied by six. Increased attendance is therefore required.

The commercial devices for control of temperature in combustion type furnaces are, at present, limited to gaseous and liquid fuels. Among the gases, raw producer gas is not controlled by automatic devices, because of the clogging effects of the tar and soot upon control valves. Among the liquid fuels, a light, clean oil is most easily controlled, whereas tar or even heavy oils, full of sediment, offer great difficulties. Powdered coal has, as far as the author knows, not been controlled automatically, although such control seems feasible.

The temperature in a furnace which is heated by coal on the grate can be controlled by adjustments of the damper, of the air blast, and of the coal feed. It is difficult to adjust these three variables in the right proportion. Such control is very seldom

used. An installation of a control system for coke on the grate was described in the *American Machinist* of Nov. 2, 1922, and in *Wärmewirtschaft*, July, 1923. This device, which was designed in Switzerland, works on the same principle as those described for gas and oil, except that the control mechanism adjusts the position of the stack damper. It is of interest to note that the controlling galvanometer is alternately and successively connected with the thermocouples of six separate furnaces by means of a very small electric motor. By this arrangement the temperature of each of the furnaces is adjusted once every three minutes.[1]

The technique of automatic control of combustion of coal on the grate and on the stokers has been highly developed in boiler firing. If the opportunity arises, the equipment developed for that purpose may be adapted to use with industrial furnaces by substituting control by thermocouples for control by steam pressure. Due attention must be paid to adjustment of secondary air for the purpose of maintaining the right furnace atmosphere.

Automatic control of furnace temperature is very successful with furnace temperatures of 1200° to 1450° F. The higher the furnace temperature, the greater are the difficulties of automatic control, because of the shorter life of the thermocouples and because of the greater time lag which is introduced by the protecting tubes. Whenever the thermocouple is burned out, automatic temperature control fails. To avoid such an occurrence the protecting tubes must be renewed frequently. The frequency of renewal increases rapidly with the temperature. Control of furnace temperature at 2200° F. has been attempted, but without success.

Up to this point only the problem mentioned under the heading (*a*) at the beginning of the chapter has been discussed. After a solution had been found for the problem of bringing the temperature of the charge up to a given value and maintaining it constant the problem of automatically varying the temperature, to follow a predetermined law or cycle, offered no difficulties.

It will be remembered that, in automatic temperature control, the galvanometer or the potentiometer has a hand adjustment

[1] The method of using one galvanometer or potentiometer for a number of furnaces can be employed just as well for furnaces heated by electricity, oil, or gas. It is, at this writing, being developed by several firms.

for the temperature which is to be reached and maintained. All that has to be done, to make the temperature follow a given time cycle, is to let a cam, driven by a motor or clock through suitable speed reducers, move the temperature-controlling adjustment in the required manner. Such a device is shown in Fig. 159. In this instrument a new gear ratio can be readily substituted to change the length of time of a cycle, or a new cam can be substituted to change the temperature relations within the cycle.

Too much should not be expected of such a device. On pages 160 to 167 reasoning was offered to show that there exist considerable differences of temperature between the furnace and various points of the charge during the heating. Attention is again called to the fact that "keeping the temperature constant" is frequently a

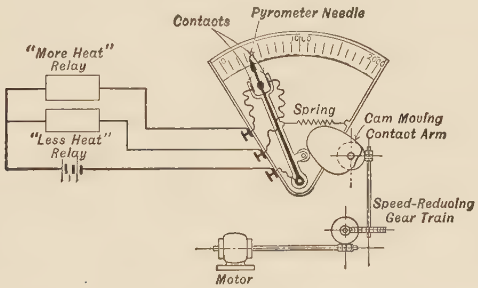

FIG. 159.—Diagram of instrument for varying furnace temperature with time according to a predetermined cycle.

misnomer. It would be more correct to speak of "allowing time for temperature equalization in the charge." Similar conditions exist in cooling. For this reason the cycle represented by the cam must be one which is adapted to the size of the heating stock or charge; in other words, it must be such that it is physically possible to accomplish the process. The time required for heating and cooling a shaft of 20 inches diameter is very much longer than that for doing the same with a shaft of one inch diameter, and the cam must be designed to take this difference into consideration. For the time required to heat or cool see pages 31 to 38 of Volume I.

At the conclusion of this chapter a word of caution may be appropriate. The best device for controlling temperature cannot produce uniformly heated stock in a poorly designed furnace.

Many of the failures that have been attributed to a control device have really been due to poor selection of furnaces to be controlled, or poor application of control devices to such furnaces. The marketing of temperature-controlling instruments involves many more problems of engineering judgment than the manufacture of the devices themselves.

There is undoubtedly a field of usefulness for temperature-control devices, but prospective users should understand that it is control of temperature of product, and not of furnaces, that is needed; that there are many furnaces which will not permit control of heat application, although they may permit control of furnace temperature. In this respect the advice of competent furnace engineers and furnace builders should weigh more heavily than the pleas of those who wish to sell control instruments.

CHAPTER IV

CONTROL OF FURNACE ATMOSPHERE

The Effect of Furnace Atmosphere.—The gases in an industrial furnace are commonly referred to as furnace atmosphere. The latter may be oxidizing, neutral, or reducing. At times obnoxious gases, such as sulphurous vapors, are present; but in industrial heating they are seldom considered, although some mysterious actions in the finishing of the material can be traced to the presence of sulphur combinations in the furnace gases.

The effects of an oxidizing atmosphere are indicated by the name. They are oxidation, scaling, and frequently sticking together of pieces of the charge due to the formation of a slag or flux. Oxidizing atmospheres are not always undesirable; they are wanted in certain ceramic furnaces and in ovens for japanning and drying. In general, industrial heating aims to impart heat only, without any chemical change. For that reason a neutral, or "indifferent," atmosphere is very desirable. However, it is well known that a so-called neutral atmosphere, consisting of nitrogen, carbon dioxide, and water vapor, is not neutral at temperatures above red heat, particularly in the presence of metals which have an affinity for oxygen. In a furnace both carbon dioxide and water vapor dissociate to a much greater extent than laboratory tests would indicate. There are several reasons for this fact. Both gases exist in the furnace at low partial pressures; and, at low pressures, dissociation is greater than it is at atmospheric pressure. Second, there is going on in gases a continual dissociation and recombination, the extent of which cannot be measured. In the presence of an easily oxidized metal dissociation still takes place, but recombination does not, because the oxygen goes to the metal instead of returning to the carbon or the hydrogen. If iron or steel is being heated, considerable oxidation is caused by water vapor, because the heat developed by the combination of unit weight of oxygen with iron is greater than that developed by combination with hydrogen.

On the other hand, oxidation by CO_2 is comparatively slow, because the heat developed by a unit of oxygen uniting with iron is only a few per cent greater than would be developed by its forming CO_2.

The rate of oxidation caused by an atmosphere containing both carbon dioxide and water vapor depends upon many variables, among which are the nature of the metal being heated, the temperature of its surface, the temperature of the gases, and their composition. Since steel is a metal which is heated in vast quantities, it might be expected that a great deal of information on its oxidation in industrial furnaces would have been gathered. That expectation notwithstanding, accurate data on the amount of scaling of steel in various kinds of atmospheres and at various temperatures are rather scarce. One of the best publications on this subject is the one by Mr. George C. McCormick in the August number of the *Transactions of the American Society of Steel Treaters*, 1922. The following table is taken from Mr. McCormick's work:

TABLE XX

SCALING IN DRY CARBON DIOXIDE

Specimens Heated from Room Temperature to 1600–1700° F. and Cooled Slowly

Experiment number	Time at 1600–1700° F.	Loss of dimensions in inches	Loss of weight in grams per square inch of surface exposed
1	2 hours	0.005	0.32
2	1 hour	0.003	0.19

Mr. McCormick did not investigate the effect of water vapor upon the scaling of steel, because that effect has been known for quite some time.

A reducing atmosphere is one that protects metal from scaling and, if it is strongly reducing (as, for instance, in the blast furnace), will convert scale or oxides back into metal. In the practice of industrial furnaces strongly reducing atmospheres are seldom

used, except for carbonizing purposes, but mildly reducing atmospheres are the ideal of every heater, because they protect the metals from excessive scaling. Whether or not a small amount of a reducing agent, such as carbon monoxide, is positive protection against scaling was another question which Mr. McCormick attempted to answer in the above-mentioned set of experiments. The following data, taken from his work, show this effect:

TABLE XXI

Extent of Scale Formation in a Slightly Reducing Atmosphere

Analysis of Gases in Furnace Chamber:

Carbon dioxide, 11.5 per cent; Oxygen, 0 per cent; Carbon monoxide, 0.8 per cent.

Temperature, 1700° F. Time, 1 hour.

Material	Loss in dimension, in inches	Loss of weight, in grams per square inch of surface exposed	Loss of weight, pounds per square foot and hour
Low-carbon steel.........	0.007	0.41	.13
Medium-carbon steel......	0.005	0.38	.12
High-carbon steel.........	0.004	0.35	.11

It will be noted from this tabulation that 0.8 per cent of carbon monoxide is not sufficient to protect the steel from scaling.

A somewhat crude, but nevertheless very significant, set of tests was published in Communication No. 41 of the Heat Economy Bureau of the German Iron and Steel Institute. That report deals with an analytical and experimental investigation of regenerative, pusher type furnaces. Tests on furnace loss were made only incidentally. Sheet bars were put on top of the regular blooms going through the furnace, and their loss in weight was determined. From these tests Table XXII was calculated.

Size of sheet bars $= 36.8 \times 9.44 \times 0.334$ inches. The area of the exposed sides was quite small compared with that of the top. For that reason the loss per square foot of surface was calculated for the top surface only.

Area of exposed top $= 2.42$ square feet.

TABLE XXII

Plate No.	Time in furnace, minutes	Original weight, pounds	Final weight, pounds	Loss, pounds	Loss, per cent	Loss, pounds per square foot while in furnace	Loss, pounds per square foot per hour	Loss in thickness, inches
1	167	28.1	21.8	6.3	22.4	2.6	0.935	0.0645
2	139	30.4	29.1	1.3	4.35	0.537	0.2315	0.0133
3	111	30.2	29.75	0.45	1.49	0.186	0.1008	0.0046

It will be noted that the loss increases very much faster than the time during which the sheet bar was in the furnace. This fact is explained by the circumstance that the sheet bars staying in the furnace a longer time were held at the hot end, where the scaling is very much greater in unit time than it is at the cold end of the furnace. The scaling in per cent is quite excessive, because the sheet bars are thin, and were laid on top of blooms which, of course, had to stay in the furnace a considerably longer time than the sheet bars would have been kept there if heated by themselves.

As previously mentioned, furnace heaters know that reducing atmospheres protect iron and steel from excessive scaling. "Keep her smoky, boys," is the slogan. Scattered tests of gases that are considered by heaters to be sufficiently reducing show from 2 to 4 per cent CO and probably traces of hydrogen. The latter gas burns from $2\frac{1}{2}$ to 3 times as fast as carbon monoxide and is, for that reason, not present in furnace gases to the same extent as carbon monoxide, except in furnaces fired with coke-oven gas. A British authority states that, with gaseous fuels, 15 per cent deficiency of air in the furnace prevents the formation of hard scale at a temperature of 2200° F.

To what extent it pays to work with reducing atmospheres is a question of dollars and cents, because reducing atmospheres cause a gain as well as a loss. The gain consists in reduced scaling; the loss consists in an increase of fuel consumption. On page 96 of Volume I, "Industrial Furnaces," data were given showing that, under average conditions, 1 per cent of carbon monoxide in

the flue gases causes a loss of 3 per cent in the heating value of the fuel. If 2 or 3 per cent of carbon monoxide in the products of combustion is necessary for protecting material such as steel from scaling, then a loss of 6 to 10 per cent of the heating value of the fuel must be countenanced. The furnace engineer, for this reason, faces a dilemma. Perfect combustion with no loss of heat due to unconsumed fuel causes heavy loss by scaling. Protection of metal by a reducing atmosphere causes loss of heat due to unconsumed fuel. A brief calculation will be of assistance in driving home the importance of this problem.

Let steel billets or forgings, which cost $40 per ton, be heated. A common figure for the furnace loss is 2 per cent. With poor combustion and long exposure of the material to hot gases, it may amount to 3 or 4 per cent. But 2 per cent of $40 equals $.80. Let 200 pounds of coal be used to heat a ton of steel, which is an average figure, and let the coal cost $3 per ton. Then the cost of the fuel for heating a ton of steel is $.30. It is at once evident that a slight difference in the furnace loss is of far greater monetary influence than the whole fuel bill. This fact explains the peculiar condition which exists in many plants. Heaters try to work with strongly reducing atmospheres so as to save furnace loss, while fuel engineers try to make adjustments for neutral products of combustion, for the purpose of saving fuel.

Other considerations enter into this study, particularly for the heating of steel. The kind of scale which is formed on steel is of importance for several manufacturing processes. There may be a light, fluffy, red scale, which rubs off easily; or there may be a thin, blue scale which sticks to the steel; or there may be a thick, black scale which is brittle and drops off easily. The thin, red, fluffy scale which rubs off easily is wanted if steel is to be pickled or tinned after it has been heated. The thin, blue scale is wanted in sheet rolling so as to prevent the sheets from sticking together in the rolling process. A scale which contains iron sulphide causes sheets to stick to the rolls in spots.[1] A scale which drops off easily and is not hammered into the steel is wanted in forging operations. Other examples of this sort could be given, but the three will be sufficient to indicate the importance of furnace atmosphere. In some cases it is impossible to obtain the proper

[1] It appears that sulphur is not absorbed by steel except when the latter is hot enough to be very soft and doughy.

atmosphere by the combustion of fuels which produce carbon monoxide only. In such cases water vapor or other vapors must be admitted to the heating chamber. In practice most fuels are hydrocarbons, and the products of combustion, therefore, contain both carbon dioxide and water vapor. An excess of hydrogen in the atmosphere apparently produces a reddish scale.

The Means for Controlling Furnace Atmosphere.—With ordinary means it is rather difficult to obtain the desired mildly reducing atmosphere which contains from 2 to 3 per cent carbon monoxide and is free from oxygen. To obtain that particular atmosphere it is necessary to provide a hair-trigger adjustment, which is unstable and changes quickly from an atmosphere that is too strongly reducing to one that is oxidizing. In this connection it is important to remember that while the flue gases passing out of the furnace may be neutral or even reducing, excessive scaling of the charge may nevertheless take place, owing to poor mixing of air and fuel and slow combustion. In order to equalize temperature throughout the furnace, stratification of gases, with delayed combustion, is frequently practiced; this is accompanied by a long, lazy flame, or by its equivalent if the furnace atmosphere is clear. As mentioned in the first volume, the long, lazy flame presupposes the presence of oxygen throughout the furnace. The uncombined oxygen attacks the material being heated, if it has a chance to come in contact with it. In consequence, furnaces in which there is delayed combustion, or in which the products of combustion strike the steel too soon, show much more scaling than is desirable. To prevent this action the fuel gas is frequently directed along the charge, while air is admitted on top of the gas under the roof, so that the charge is virtually bathed in gas, while the roof is supposed to be kept cool by the air. In a few designs air is admitted in stages through the roof, and combustion takes place in the measure in which fuel and air mix. In addition, it is, of course, necessary to maintain a slight pressure in the furnace all the way down to the hearth so as to prevent air infiltration. If that is not done the oxygen in the entering air produces scaling in unsuspected places.

In the treatment of control of furnace atmosphere a distinction must be made between fuel-heated furnaces and electrically heated furnaces. The present section will deal with fuel-heated furnaces. No matter what the method of combustion and of mixing of fuel

and air may be, the maintaining of a constant furnace atmosphere with varying rates of fuel supply requires a constant fuel-to-air ratio. A constant furnace pressure is of great assistance. The same thought may be expressed differently thus: If the temperature of the furnace, or the amount of heat delivered to the furnace, is to be varied, and if the furnace atmosphere is to be kept constant, then there are necessary adjustments of (1) the rate of air delivery, (2) the rate of fuel delivery, and (3) the opening of the vent damper or dampers. If the composition of the fuel varies with time, additional adjustment becomes necessary. In practice it is often extremely difficult to comply with these requirements. In discussing this statement consider first the vent dampers. The latter are frequently not adjusted, where they have been provided, and, in many furnaces, are conspicuous by their absence. These facts are doubtless due to the circumstance that simultaneous adjustment of many dampers by automatic means calls for a considerable amount of complicated mechanism, which is hard to keep in shape on top of a furnace. Besides, fairly good, although not perfect, results can be obtained by having vent openings of a constant size, particularly in furnaces which work with an almost constant rate of heating. Increased rate of heating (with constant vent opening) results in increased furnace pressure and in blowing of furnace gases out of the doors and peep holes. It should, however, be understood that the omission of automatic control of dampers is not correct engineering from the fuel standpoint, but is only a makeshift dictated by the desire for simplicity. Very often tiles are placed over the vent openings, and a manual adjustment is effected.

The commonest method of adjusting furnace atmosphere with regard to the ratio of fuel to air, consists in letting the eye of the heater decide whether the atmosphere in the furnace is reducing, neutral, or oxidizing. With a few fuels that decision is comparatively easy, because a reducing atmosphere is smoky and hazy if cold combustion air is used, whereas a clear, transparent " heat " indicates a neutral or oxidizing atmosphere. In this difference lies the reason why so many heaters maintain smoky atmospheres in their furnaces. With a few fuels, such as coke-oven gas, blue water gas, or clean producer gas, it is practically impossible to judge the chemical character of the atmosphere by the eye. From the standpoint of the combustion engineer it is, of course, desirable

in either case to depend upon a flue-gas analysis made by means of an Orsat apparatus or, better still, by means of an automatic flue-gas composition recorder. It is rather unfortunate that, up to the present time, no simple oxygen recorder has been invented, because, if such a recorder existed, the rules and regulations for the heater would be to work without any oxygen in the products of combustion. Comparatively simple electrical indicators showing combustible matter in the products of combustion are now on the market. For large furnaces and important work their use reduces both scaling of stock and consumption of fuel.[1]

A better method than depending upon the eye of the heater consists in furnishing him with apparatus for maintaining a constant fuel-to-air ratio, and in checking the operation of this apparatus at regular intervals by means of flue-gas analyzing equipment. With such a method of control, which is more or less automatic, a difference must be made between gaseous fuels, liquid fuels, and solid fuels. It is a fortunate coincidence that correct and automatic proportioning of air and fuel is easiest in the case of gaseous fuels, with which it is most difficult for the heater to judge the character of the atmosphere from the appearance of the furnace interior. The problem of automatic proportioning is more difficult with liquid fuels, and still more difficult with solid fuels. A difference must also be made between furnaces heated by one burner and those heated by two or more burners.

Atmosphere Control with Gaseous Fuels.—With any fuel the most natural and obvious step towards control of furnace atmosphere consists in mechanical inter-connection of fuel supply and air supply. Inter-connected valves for air and gas are shown in Fig. 160. It will be noted that adjustments have been provided for difference of valve opening and also for relative rates of valve opening. Devices of this sort have been tried very often and have been discarded in the great majority of cases because the conditions which are necessary for their success were not provided. These conditions are: (1) constant gas pressure, (2) constant air pressure, (3) constant gas quality, (4) constant gas temperature, (5) constant air temperature. Even slight variations in these quantities are enough to upset the hair-trigger adjustment of

[1] For a description of these instruments, see *Fuels and Furnaces*, October, 1923, page 471.

correct fuel-to-air ratio. If such variations occur, the heater disconnects the valves and goes back to hand adjustment, guided by the appearance of the furnace.

This situation has lately become of importance, because automatic temperature-control apparatus is frequently designed with inter-connected air and fuel valves, and because these devices are commonly supposed to control not only furnace temperature, but also furnace atmosphere.

Even if the above-mentioned conditions are met, inter-connected valves may fail to insure the continuance of a correct furnace atmosphere. For a proof of this statement consider the case in which the blast air passes through a regenerator on its way to the furnace. Reversing valves and regenerators are leaky; brickwork is full of cracks and pores. Expansion and contraction vary the degree of leakiness. In consequence, a variable fraction of the air passing through the control valve reaches the furnace.

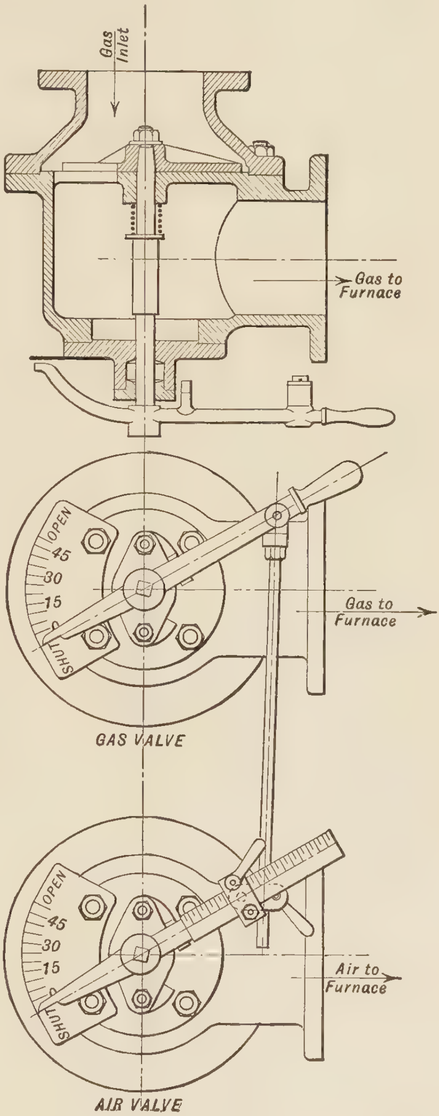

Fig. 160.—Inter-connected air and gas valves.

Note adjustment for variation of relative openings.

Frequent checking of the flue-gas analysis and resetting of the valve linkage are obviously very necessary in such a case. If these precautions are not taken the heater will disconnect the valves.

In any automatic device for control of furnace atmosphere it is necessary that the ratio of fuel to air be capable of easy adjustment during the operation of the furnace, so that the operator may change from a reducing flame to a neutral or oxidizing flame, or may compensate for variations in the composition of the fuel gas. It is also desirable that, after this ratio has been adjusted manually, it should remain constant during the automatic operation of the apparatus.

In contradistinction to the devices with inter-connected valves, whether they be operated by hand or by an automatic temperature control, there are a large number of devices on the market in which the ratio of gas to air is controlled by other means. These devices, some of which were mentioned under "Combustion Devices for Gaseous Fuels," are usually referred to as proportional mixers. Their number is increasing so rapidly that it is not possible to describe all of them. However, it is advisable to describe a few of the typical designs for the sake of bringing out the underlying principles. In most of the proportional mixers the gas is reduced to atmospheric pressure by a reducing valve before it enters the mixer proper. Gas and air flow through a proportional mixing valve, which is similar to that used on gas engines. The term "proportional" indicates that the ratio of the gas port to the air port is constant for any position of the valve. The mixture is sucked through the valve by a fan, a jet, or a rotary blower, and is delivered to the furnace by the pressure of these pumping devices. If the gas-pressure regulator works well, both fuel and air are indeed taken in at equal pressures. However, the condition of correct working of the pressure regulator is not easily fulfilled if the gas arrives at a considerable pressure and if it contains traces of gumming or sticky substances. These substances cause the reducing valve to stick, and interfere with regulation, because the valve works in the almost closed position. No trouble arises if the valve works continually in an open position.

Figures 161, 162, and 163 show proportional mixers in which the movement of the mixture is caused, respectively, by a positive

blower, a fan, and a jet. If the rate of heating is low, and if the mixture of gas and air is almost correct for perfect combustion, back-firing occurs. In long pipe lines this occurrence means quite a disturbance in the operation and sometimes damage to the equipment. For that reason the mixture is often made too rich in fuel, and additional air is induced by the mixture passing through a nozzle at the furnace. This arrangement does away with the back-flares, but it also does away with the positiveness of atmosphere control. In the arrangement of Fig. 161 the induction of air at the furnace is openly advocated by the builders of

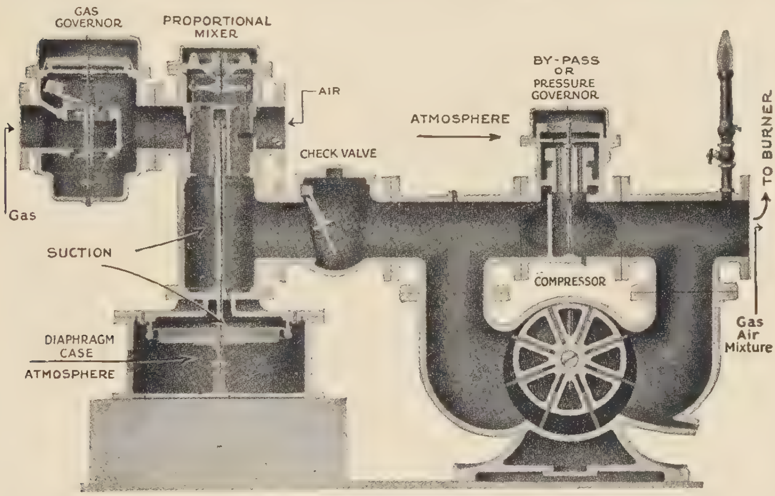

FIG. 161.—Proportional air and gas mixer with positive blower. The mixture is rich in gas and is practically non-explosive.

the equipment. With the arrangement of Fig. 162 it is not advocated, but is commonly practiced. With the arrangement of Fig. 163 it is not necessary, because the injecting jet and the mixing cone can be placed right against the furnace.

In Fig. 161 the valve which reduces the pressure of the gas to that of the atmosphere is shown, whereas it is omitted in Figs. 162 and 163. Its use is, of course, necessary in all of these devices. Its application to the mixer represented by Fig. 163 is depicted in Fig. 164, which is a perspective view of Fig. 163. The mixing valve in Fig. 161 is operated by a diaphragm, which, in turn, is affected by the suction pressure created by the pump

or compressor, in such a manner that a greater demand for mixture raises the parts in the mixer. This arrangement is necessitated by the fact that a displacement pump (such as is used in this system) takes in a practically constant suction volume. The quantity which is delivered in unit time is varied either by a greater suction ahead of the pump, or by letting some of the fluid pass back from the delivery side to the suction side. The pressure on the delivery side of the compressor is kept constant by a diaphragm-controlled by-pass. A check valve prevents injury to the suction diaphragm in case no gas is used. In this mixer, only about one-half of the combustion air is mixed with the gas. The mixture is then used in induction burners, which are somewhat similar to the Koerting Air Injector. From the statements on page 44 of Chapter II, it can be seen that air induction is very much less liable to a variation if the quantity of induced air is small compared with the quantity of the inducing medium. By virtue of these facts, the system illustrated in Fig. 161 is useful as a correct proportionator; the volume of gas plus air delivered by the compressors is large in comparison to the quantity of secondary air which is induced at the furnace.

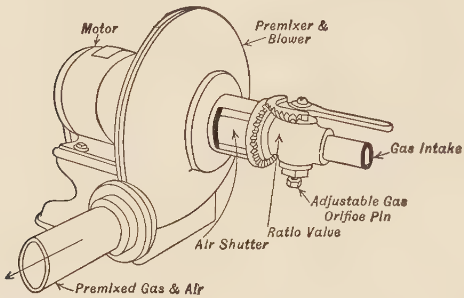

FIG. 162.—Proportional air and gas mixer using fan blower.

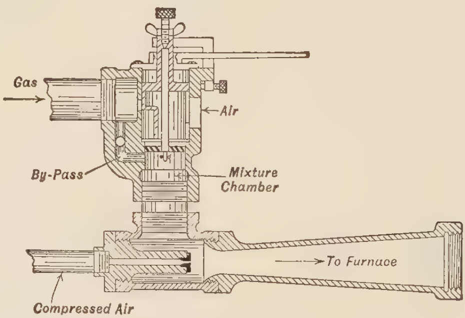

FIG. 163.—Proportional air and gas mixer. A jet of compressed air drives the mixture into the furnace.

The proportioning system illustrated in Fig. 161 is only one out of several which are based on the same principles, and which

differ only in design of details. The fact that it is selected for description should not be construed to mean that it is the best on the market. There exist several systems which deliver a non-explosive mixture of gas and air of constant proportions to an inspirator-burner. The inspirator which is used with one of these systems is shown in Fig. 43.

In these systems, which use a positive blower for pumping the gas and air mixture, it is possible to deliver that mixture at fairly high velocity. This fact makes induction more or less independent of variation of back pressure in the furnace, and tends to maintain the correct mixture of air and gas in the furnace. In addition, the control of one valve, namely, the gas-and-air mixture valve, automatically admits more or less in definite proportions, by which circumstance the adjustment is made independent of the whims of the heater or of his watchfulness. Control of the furnace atmosphere is effected by adjustment of the ratio of the gas ports to the air ports in the proportional mixer.

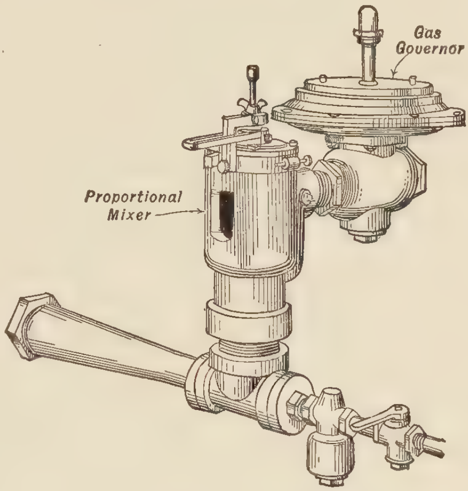

FIG. 164.—Perspective view of proportional mixer shown in Fig. 163.
Note gas-pressure governor.

With regard to the mixer illustrated by Fig. 162 the following should be noted. An ordinary fan does not produce a pressure in excess of 6 inches of water. In consequence, the pressure drop from the fan, through the delivery pipe and the burner nozzle, cannot exceed that amount at the highest rate of delivery. For that reason the velocity of flow is limited, and becomes very low at small rates of gas delivery, so low that lighting back must be expected, if the mixture is correct for perfect combustion. While the open construction of the fan prevents damage to the equip-

ment from an explosion, regular operation is impossible with back-firing. For that reason most combustion engineers prefer to produce a mixture which is not rich enough in air at the fan, and to let this mixture induce secondary combustion air at the furnace. As above stated, control of furnace atmosphere is not automatic in that case. The fan mixer under discussion shares with all other proportional mixers the requirement that the ratio of gas to air be adjustable, and yet that proportionality of the mixture be maintained at all times regardless of the adjustment. With the fan, this can be done, for instance, by varying the axial length of the opening of the air-inlet sleeve. This adjustment is necessary not only because it may be desired to vary the nature of the products of combustion from oxidizing to neutral or reducing, but also because the same fan is used for different gaseous fuels.

Some of the statements of the preceding paragraph become void if mixer fans are used which produce pressures much in excess of 6 inches of water. Proportional fan-type mixers, which deliver air-and-gas mixture against pressures of 34 inches of water, are now on the market. A mixer of this type is illustrated in Fig. 165. With this fan, the danger of back-firing is practically absent. Nevertheless, an explosion door has been provided at the fan inlet. It is clearly visible in the illustration.

In the mixer represented in Fig. 163 a small amount of gas is by-passed at the left, through the elbow, around the proportional mixer, so that, as a matter of fact, the gas-and-air mixture passing from the proportionator to the air nozzle is a little bit too rich. At the bottom, at the left-hand side, a small stream of high-pressure air enters the mixer, causing a suction in the mixture chamber, re-establishing the correct air to gas ratio, and propelling the mixture through a divergent tube, whence it passes to the burner or burners. The area of the gas by-pass and the area of the air-jet nozzle are so selected that correct mixture is maintained over a considerable range of flow. The flow of gas and air is controlled by a handle at the top of the proportioning valve. This mixer delivers an explosive mixture of correct proportions to the furnace, but it can be set close to the furnace and does not carry the explosive mixture any considerable distance. At the throat of the divergent tube the velocity is so high that even at

the lowest rate of delivery it is impossible for the flame to blow back beyond the throat.

In a different type of proportional mixer the proportioning valve is done away with, and the property of an aspirating Venturi tube which enables it to act both as pump and as proportioning

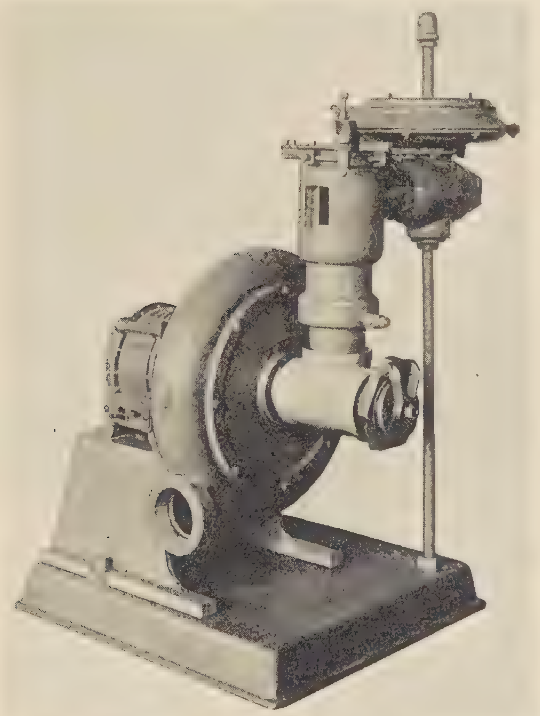

FIG. 165.—Proportional mixer of the fan type. It generates pressure up to 34 inches of water and can handle explosive gas-and-air mixtures, with practically no danger of back-firing.

device is utilized. The principle of such a mixer is diagrammatically illustrated in Fig. 166. Since either the gas or the air can be used as the inducing medium, they will for a while be designated as fluid No. 1 and fluid No. 2. Fluid No. 1 arrives at an adjustable pressure and passes through a nozzle into the throat of the Venturi tube. By its velocity and viscous drag it induces fluid No. 2, which, as a rule, is delivered at atmospheric

pressure. Thorough mixing occurs in the throat and in the divergent part of the Venturi tube, and the mixture of gas and air is delivered against some back pressure. By careful proportioning of the inlet nozzle with regard to the throat of the Venturi tube and by proper location of the inlet nozzle, the gas-to-air ratio can be made to remain constant over a remarkably wide range of pressures and velocities of fluid No. 1. The apparatus is sensitive to variations in the back pressure, but, with properly designed furnaces and burners, back pressure is a function of the quantity of fluid No. 1 passing through the mixer in unit time, and can be compensated for in the design of the mixer. Several proportional mixers based upon this principle are on the market. Figure 167 shows a type in which air at $\frac{1}{4}$ pound per square inch to about 2 pounds per square inch pressure can be used as the inducing medium. The air enters at the place marked "air inlet," after passing through an adjustable valve. Gas enters from the right, and is once for all adjusted by the thumb screw shown at the left. The mixture delivery takes place at the left, and the makers claim that the gas-to-air ratio remains constant over a wide range of turndown of the air-inlet valve. A gas shut-off valve is, of course, provided, but it is to be left wide open, and not to be touched during regular operation of the apparatus. Variation of gas flow is effected by adjustment of a globe valve in the air line.

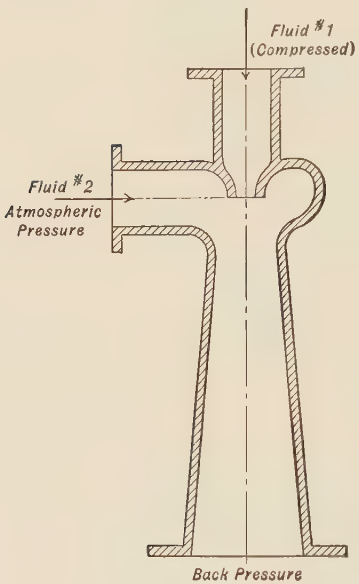

FIG. 166.—Diagram of Venturi tube inspirator and proportional mixer.

Figure 168 illustrates a mixer which is based on exactly the same principles with the difference that the inducing medium enters the throat of the Venturi tube through small radial holes at the throat of that tube. In all other features and in the mode of operation it is exactly the same as that shown in Fig. 167.

The system in which air under some pressure induces the gas is very useful for rich gases, such as natural gas, coke-oven gas, or water gas, provided these gases are clean. If, on the other hand, leaner gases, such as blast-furnace gas, clean producer gas, or carbo-gas, are used, it is often more convenient to subject the gas to some pressure and to let it induce air directly from the atmosphere. This system is also used if the gas has gummy constituents which would interfere with the correct operation of a

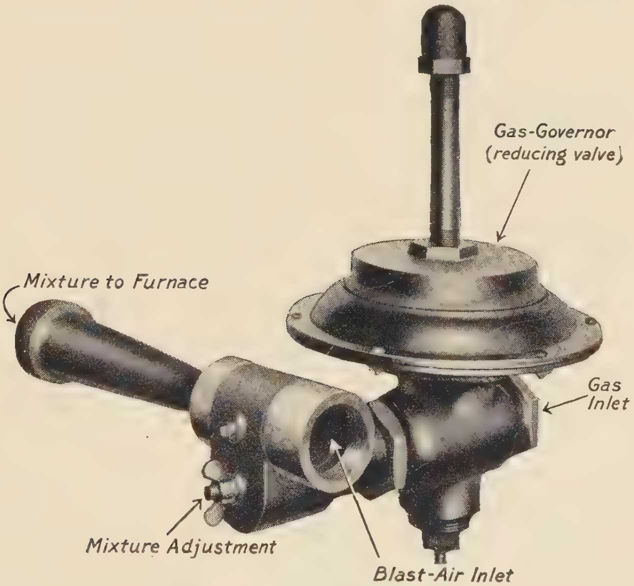

Fig. 167.—Venturi tube proportional mixer operated by fan-blast air.

governing valve. A mixer built on this principle is shown in Fig. 169. The only adjustment which is required in regular operation is that of turning the globe valve on the gas line. Adjustment of the character of the flame is obtained by putting a restriction into the air inlet, for instance, by turning the shutter down, as in the illustration. The last-mentioned mixer is very well suited for dirty coke-oven gas, because it does away with the necessity of a gas-pressure regulator. A gas compressor with an unloader is required, but it is not put out of commission by the dirt in the gas, by which the gas-pressure regulator, as before

mentioned, is clogged and made inoperative. There are, however, gas regulators on the market which are (according to statements of the builders) not affected by dirt in the gas.

The statement was made on page 202 that variation of back

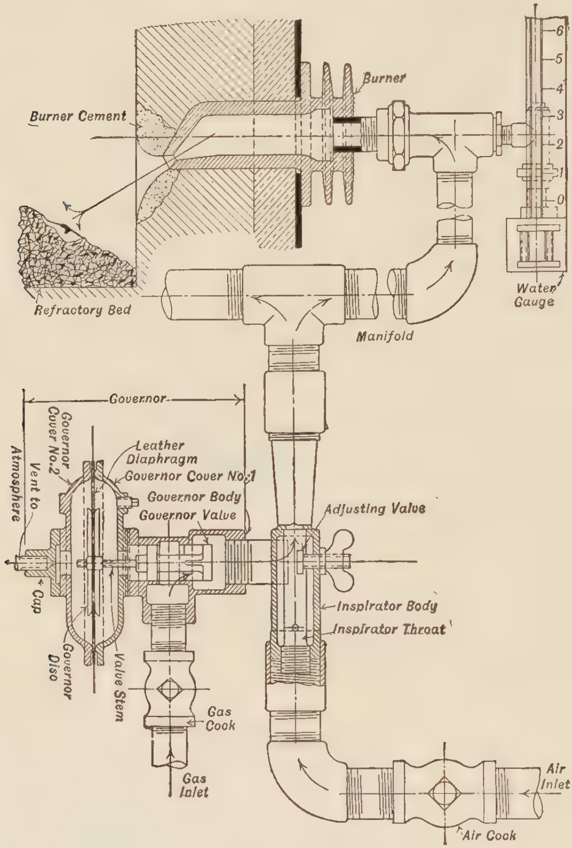

FIG. 168.—Proportional mixer of the Venturi tube type.
Note gas governor, gas manifold, and burner.

pressure has a very decided influence upon the fuel-to-air ratio in the inspirator mixers. By working with a high velocity of the mixture in a burner such as is shown in Figs. 168 and 169, any variation of back pressure in the furnace becomes quite negligible compared with the definite variation of back pressure as a function

of flow of gas and air. The design of the inspirator burner must then be such as to compensate for that known variation of back pressure.

While in the Venturi inspirators shown in Figs. 167 to 169 the design is such that the ratio of gas to air varies very little over a wide range of turn-down, it does not remain absolutely constant.

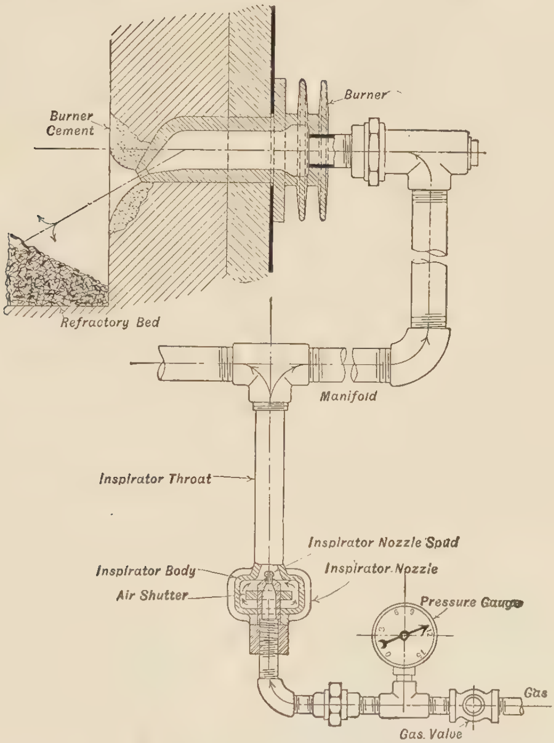

FIG. 169.—High pressure inspirator. Gas under pressure entrains air and mixes with it in a slender Venturi tube.

The mathematical investigation of the relations determining the proportionality is extremely difficult and does not give an answer in general terms. For that reason, experimental work must be relied upon, and that work is costly, on account of the large number of variables entering into it. Such experiments show that there is indeed a lack of proportionality if a very wide range of gas flow is desired. This fact caused a British engineer to devise

a means by which the proportionality can be extended over a still wider range. His design is shown in Fig. 170. The mixer is of the type shown in Figs. 166, 167, and 168, in which air induces the gas. The difference consists in putting into the injection tube a rotatable pipe, the lower end of which is cut on the diagonal. The static head and part of the dynamic head of the fluid passing through the expanding tube then act upon the gas regulator and vary the pressure with which the gas enters the outer section of the Venturi tube. By a partial rotation of the inclined-cut tube in the nozzle, the dynamic head can be adjusted, and the tendency to give too much gas at high rates of flow can be counteracted. While this device has been commercialized in England it is not on the American market, as far as the author knows. A similar effect has, however, been obtained on the proportional mixer shown in Fig. 167, by transmitting a slight pressure from the inlet of the Venturi tube to the gas regulator.

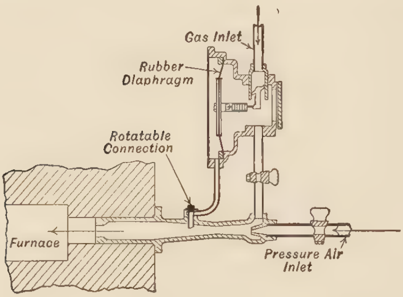

Fig. 170.—Proportional mixer of the inspirator type. Proportionality is maintained over the whole range of flow.

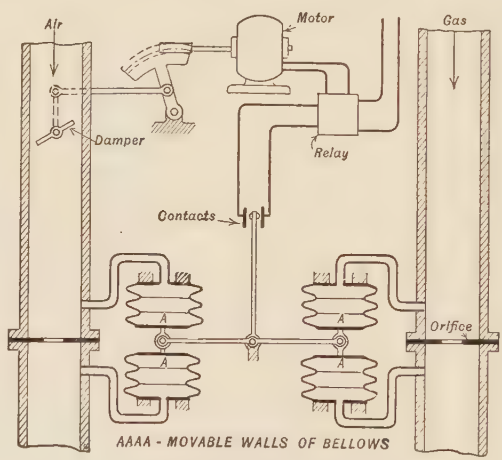

Fig. 171.—Diagram of proportioning device, based on equality of pressure drops through orifices.

Still another and quite different principle has been used for the purpose of securing proportionality between gas and air flow at all rates of gas flow. It is illustrated diagrammatically in Fig.

171. It is based on the fact that a fluid passing through an orifice produces a pressure-drop which is practically proportional to the square of the velocity of flow, provided the fluid has a low viscosity. In the illustration, air flows through the pipe shown on the left, while gas flows through the one shown on the right. Each pipe carries an orifice, and the pressure-drops through the two orifices, by acting on diaphragms or floats, cause forces which are pitted against each other. The orifices must be so selected that, with the correct ratio of gas to air, the forces caused by the pressure differences of the two orifices just counterbalance each other. If either too much or too little air is flowing, in proportion to the flow of gas, the forces become unbalanced and a relay is set into motion. In the illustration contact is made on one side or the other of a sensitive electric switch. By means of an electric relay an electric motor is started in one direction or the other, and turns a butterfly valve, thereby adjusting the air flow until the correct ratio of gas to air has again been obtained. The various parts are so clearly shown in the illustration that no further comment is necessary. The ratio of gas to air can be varied by changing the size of either one of the two orifice plates. If a variation or adjustment is to be obtained while the equipment is in operation, one of the orifices can be made adjustable, for instance, by a slide which can be operated from the outside.

In an American adaptation of this principle, shown in Fig. 172, Venturi meters are placed in by-passes around the orifices. It has thus been possible to obtain a greater pressure difference for moving the relay than can be furnished by orifices. In the illustrations the Venturi meters are marked " air Venturi " and " gas Venturi." A pipe leads from the upstream end and from the throat of each Venturi to a bellows or diaphragm. The forces on the bellows counteract each other by acting on a bifurcated lever. If the two pressure differences are out of balance the lever turns, moving a small pilot valve. The motion of the latter admits blast air to one side or the other of a diaphragm which is located in what is called the operating valve. The force on that diaphragm adjusts the butterfly valve in the air line, whereby proportionality between gas flow and air flow is again restored. The proportionator under discussion has one feature in common with all others, namely, that adjustment of the gas flow and of the air flow is obtained by adjustment of a valve in the gas line only. The

design illustrated by Fig. 172 is very good for clean gas and clean air, but should never be used for a gas which deposits dirt, such as tar or naphtha, in the Venturi tube, because the pressure-drop through that tube is very much increased by a reduction in the diameter of the throat. The original design, shown diagrammatically in Fig. 171, is suitable for dirty gas.

Up to this point no distinction has been made between fur-

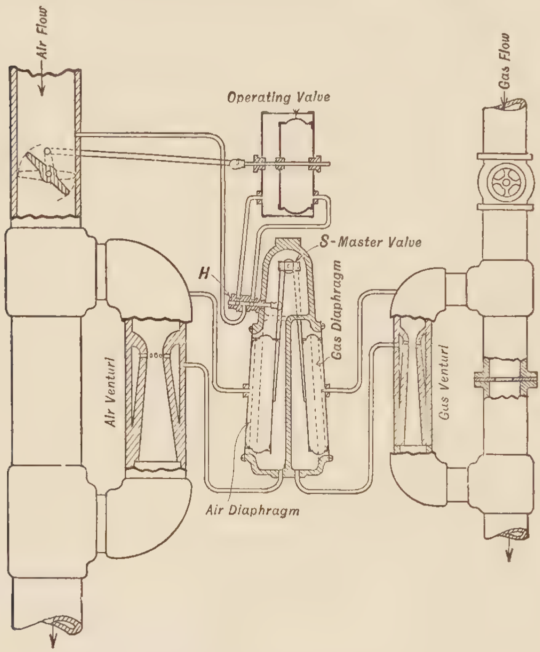

FIG. 172.—Diagram of proportioning device, based upon equality of pressure drops in Venturi tubes.

naces with individual burners and those with a multiplicity of burners. The number of burners causes no difference, if the correct explosive mixture is delivered to each burner from a common header; if, on the other hand, manually controlled mixers or two-pipe systems are used, atmosphere control becomes difficult if more than one burner is used. The difficulty is this: the flue gases leaving the furnace may have the correct composition (no oxygen, and a small amount of combustible) and yet the gases may be very oxidizing in front of some

of the burners, the difference being made up by a strongly reducing atmosphere coming from the rest of the burners. This difficulty is very real, but it can, to a certain extent, be overcome. If the two-pipe system with a proportional meter, such as that illustrated in Fig. 171, is used, gas and air flow can be regulated at each burner by means of flue-gas analyzing apparatus, and the total flow can be regulated by one valve. The same thing can be done if gas and air are controlled by inter-connected valves. If a system such as that illustrated by Fig. 161 is used it is likewise advisable to adjust the air induction of each burner by means of flue-gas analysis near the burner, and to vary the supply of heat to the furnace by the adjustment of one valve.

Up to the present time no means for automatic control of furnace atmosphere has been devised if raw producer gas serves as fuel; soot and tar in the gas clog up any automatic control valve. If one producer or a group of producers serves a single furnace, the pressure of the steam which operates the blowers of the producers and the combustion air to the furnace are occasionally controlled simultaneously. However, the results are poor, because a given steam pressure does not produce gas at a given rate. If, in addition, raw producer gas and air must be admitted through many ports, as, for instance, in the continuous furnace for long bars shown in Fig. 173, the eye and judgment of the heater are the only means of control of atmosphere, because automatic control is utterly impossible. In this case the heater watches the bars as they come out of the furnace. The color of the bar at various points along its length tells him how to adjust the valves for supply of heat, while the distribution of scale along the bar tells him how to adjust the valves for fuel-to-air ratio. This case is very much complicated by the requirement that the temperature at different points of the bar should vary. The latter requirement is imposed by the desire to have all parts of the bar fill the grooves in the rolls of the mill. It is very complicated and cannot be discussed in detail in this volume.

The problem of controlling furnace atmosphere, if the combustion air is preheated, is very far from a satisfactory solution. If the temperature of the preheated air could be maintained constant, independent of the rate of heat delivery to the furnace, the problem would be no different from that which exists with cold combustion air, except that hot, explosive mixtures cannot be

carried in pipes, on account of the much increased tendency to light back and explode. But a constant temperature of the preheated air cannot be guaranteed, except by complicated thermostatic control apparatus, which engineers are unwilling to apply. The first cost of such equipment is considerable and its maintenance cost is high. If absolutely tight recuperators or re-

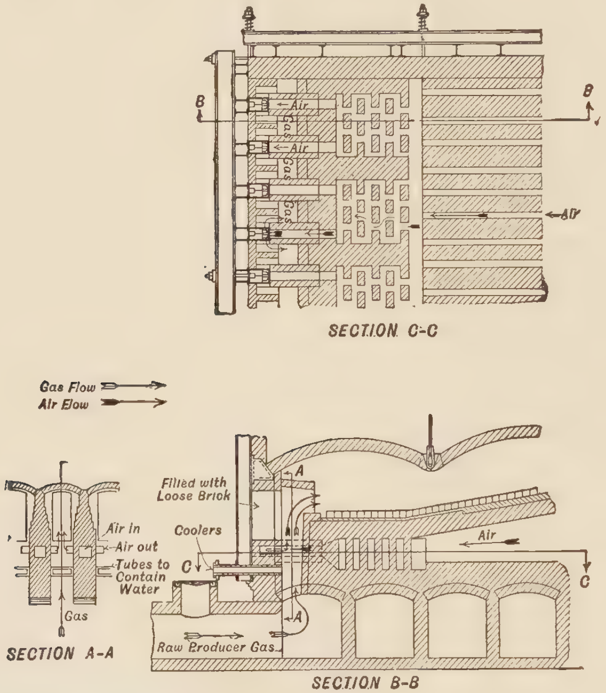

FIG. 173.—Continuous furnace for heating long bars. Many burners are arranged side by side. Furnace atmosphere is adjusted by the judgment of the heater.

generators are employed, the metering of the air for proportioning purposes should be done before the air enters the preheater.

Automatic control of furnace atmosphere with gas of fluctuating composition is quite difficult, and calls for complicated apparatus, if the fluctuations of the heating value and of the density of the gas are severe. A very interesting solution, in the case of a furnace which was supplied with coke-oven gas, retort gas, and

carbureted water gas, was described in *Fuels and Furnaces*, January, February, and March, 1924.

Atmosphere Control with Liquid Fuels.—In the introduction to this chapter the statement was made that it is more difficult to control a furnace atmosphere with liquid fuels than with gaseous fuels. The simplest method of control consists, obviously, in inter-connecting the oil valve and the air valve. That arrangement is used in the automatic devices for the control of temperature; but while the flow of a gas depends mainly upon its pressure and upon its specific gravity, the flow of oils depends, in addition to pressure and specific gravity, upon its viscosity, and the latter varies not only with the temperature of the oil but also with its chemical composition. From these facts it stands to reason that if a satisfactory automatic control of furnace atmosphere is to be obtained with oil as fuel, not only oil pressure and air pressure, but also the viscosity of the oil, must be kept constant. Since the latter varies very much with the temperature of the oil it is evident that automatic control of furnace atmosphere with oil-fired furnaces can be obtained only if oil pressure and also oil temperature are kept absolutely constant and unvarying. These statements refer to oil pressure and oil temperature at the flow-controlling device and not at some other place; this distinction is important. The oil pressure may be kept constant at the pump and yet may vary at the controlling device on account of the varying condition of the strainers, which become clogged up as time goes on. The oil temperature may be kept constant at the heater and yet may vary at the flow-controlling device on account of the varying rate of cooling of the oil, depending upon the rate at which oil flows through the pipes from the heater to the controlling device. Lack of observation of these simple facts has brought practically all atmosphere-controlling devices for oil into disrepute.

In view of these numerous difficulties it is no wonder that no commercial system for control of furnace atmosphere is in use for liquid fuels. Devices have been invented, and are being marketed, for controlling simultaneously the flow of oil and the flow of atomizing air or steam. Such a device is shown in Fig. 174. It will be noted that the adjustment of one handwheel controls the supply of liquid fuel and of atomizing fluid. Such devices, however, cannot properly be called equipment for control of furnace

atmosphere. Fortunately, the eye of the heater is a better guide to furnace atmosphere when liquid fuels are burned than it is when gaseous fuels are used. Most of the liquid fuels contain very heavy hydrocarbons, which have a tendency to produce smoke as soon as there is a marked deficiency of air in the furnace, particularly if cold air is supplied for combustion. In consequence, the heater varies the air supply until the furnace atmosphere has a sufficiently hazy appearance. For a given deficiency of air, this hazy appearance varies with the temperature of the combustion air. On that account it is very desirable that, from time to time, the flue-gas analysis be checked by an Orsat apparatus, so that the heater may be in position to compare the appearance of the furnace atmosphere with the actual flue-gas analysis. With important furnaces or furnaces of large size, it would be very desirable to provide automatic flue-gas analyzing apparatus, such as that mentioned above, under "Furnace Atmosphere Control for Gaseous Fuels." The electrical instrument based upon catalytic combustion and the principle of the Wheatstone bridge seems particularly well adapted to this purpose.

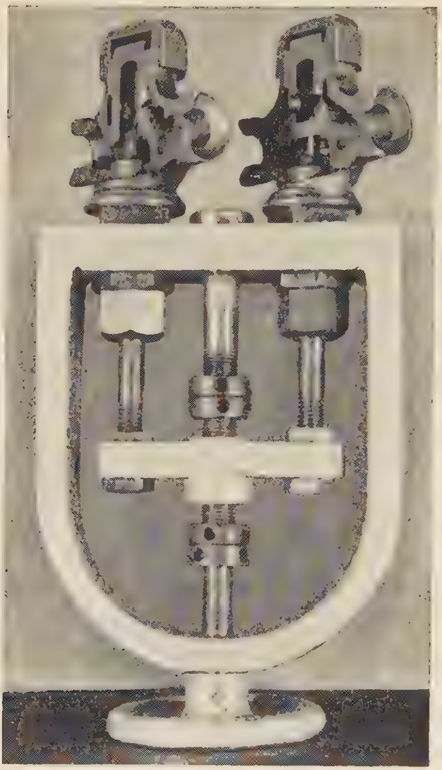

Fig. 174.—Regulator for proportioning flow of fuel oil and of atomizing steam.

For the reason above given, flue-gas analyzing apparatus should be relied upon even if all of the combustion air is furnished by a blast, and if an automatic temperature control device is

provided. On account of the solid matter carried by the liquid fuel it is practically impossible to maintain constant flow of oil or tar for a given opening of the restriction in the temperature-controlling device. In consequence, the supply of liquid fuel varies and the furnace atmosphere departs from the correct adjustment. Furnace temperature is maintained by an increased opening of the fuel and air valves, and the fuel supply is restored to its former value, while the air supply is increased. Since the change from a slightly reducing to a slightly oxidizing atmosphere is a hair-trigger adjustment, constant supervision is necessary, in spite of automatic temperature control. This statement should not be construed to mean that equipment for keeping oil pressure, oil temperature, and blast pressure constant, is superfluous. On the contrary, such equipment is very necessary, because without it the flame may change from one foot in length to six feet in length in a few minutes. After it has been adjusted back to the right length it may become so small that it almost disappears, or may even blow out.

While electrical flue-gas analyzing equipment has apparently not been used, up to the present time, for the automatic control of furnace atmosphere, its use can easily be imagined. The depressor bar instrument, which now records $CO+H_2$, can be used for varying the supply of air, so that a constant flue-gas analysis is maintained in the same manner in which the depressor bar recorder of a pyrometer maintains constant temperature. Such instruments would not be difficult of design, and it is hoped that someone will have the courage to develop one and put it on the market. Such a device could be used equally well for gaseous, liquid, and solid fuels. At the present time the maintaining of constant oil pressure, constant oil temperature, and constant blast pressure, together with frequent cleaning of the strainers, offers the greatest chance of maintaining a constant atmosphere, particularly in conjunction with an automatic temperature-controlling device.

The statements which were made about dampers under the heading "Control of Furnace Atmosphere with Gaseous Fuels" likewise apply to liquid fuels. By rights there should be automatic control of the dampers also on furnaces fired with liquid fuel. This control is intricate, for the same reasons which hold with gaseous fuel.

Control of Furnace Atmosphere with Solid Fuels.—With solid fuels burning on a grate, control of furnace atmosphere is rather difficult, although by no means impossible. In fact, a very skillful heater may, with certain types of furnaces, produce a very good reducing atmosphere with hand firing. It is a well-known fact that air, passing through a fuel bed, first burns the carbon to CO_2, and that part of the latter is reduced to CO in the upper layers of the bed, so that the gases leaving the fuel bed contain a considerable amount of combustible matter. With a deep fuel bed, and good lump coal, and with the proper location of the grate or with a slight blast through the fuel bed, it is possible to maintain a reducing atmosphere directly over the hearth of a furnace, particularly if the products of combustion travel a long distance before they reach the charge. It is also possible to so arrange the grate and the path of the gases through the furnace that there is very little contact between the products of combustion and the charge. Such a design is shown in Fig. 175, which diagrammatically represents a sheet-heating furnace. This illustration is identical with Fig. 253 of Volume I. The atmosphere in the furnace will remain reasonably constant, as long as high-grade lump coal of uniform kind and size is used, the same depth of fuel bed is maintained, the fuel bed is kept uniformly clean from ashes and clinkers, and the position of the damper on top of the stack remains the same. There is an advantage in the use of large lumps of coal, because most of the sulphur is removed with the fines. As the remaining lump coal contains comparatively little sulphur, there is only a small volume of sulphurous gases in the heating furnace. As may be seen from this description, the maintaining of constant furnace atmosphere in a hand-fired furnace is anything but automatic. It depends almost entirely upon the ability, the attention, and the good will of the heater. Since the remuneration which heaters receive is rather meager, good hand firing is the exception rather than the rule.

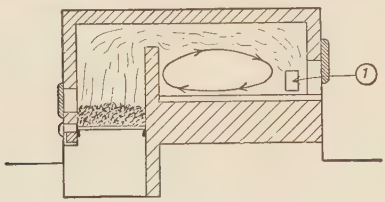

Fig. 175.—Diagram of sheet furnace. Most of the products of combustion pass through the furnace without coming in contact with the sheets.

Conditions are very similar with regard to stoker-fired indus-

trial furnaces. Very little need be added here to what was stated in Chapter II under the heading of "Stoker-fired Furnaces." With stokers, a poorer grade of coal, namely, slack, or run of mine, is usually employed. When this is used, the fuel bed does not allow the passage of sufficient air for combustion of the gases given out at its top, and a considerable portion of the combustion air must be admitted through openings above the fuel bed. To make the control of furnace atmosphere in stoker-fired furnaces automatic, the coal feed, the air delivery below the grate, and the delivery above the grate should be inter-connected, and should be very carefully adjusted. If they are not properly adjusted the fuel bed will either become thicker and thicker or else it will burn thinner and cause thin spots in the fire. On account of varying ash content and of clinker formation it is almost impossible to maintain the correct atmosphere automatically for any length of time. From time to time the heater must check up the thickness of the fuel bed and must satisfy himself that it is still correct. Since a heater is necessary in any event, and since he must continually check up the fuel bed, automatic control of furnace atmosphere, with mechanical stokers, is attempted in very few places. It is possible to realize automatic control by means of meters for CO_2, CO, and O_2, which control air admission above the fuel bed. Such devices have been proposed, but have not been introduced commercially.

With powdered coal, accurate control of furnace atmosphere is easier than it is with coal on the grate, because the flow of fuel can be regulated with some degree of accuracy. By the same reasoning which was given in the case of gaseous fuels and of liquid fuels it follows that there should be proportionality between the quantity of powdered coal entering the combustion chamber in unit time and the supply of combustion air. In practice, it is quite difficult to bring about this desirable state of affairs for varying rates of heating, because the flow of coal and the flow of air follow very different laws, and because two separate streams of air call for adjustment, namely, the primary air (or emulsion air) which carries the coal in suspension, and the secondary air which is admitted at the furnace. For constant rate of coal delivery these quantities can be adjusted nicely, with the eye of the heater or the flue-gas analyzing apparatus as a guide. With varying rates of coal delivery the air adjustment is tedious,

if made by hand. While automatic adjustment would be very desirable, the art has not progressed far enough to produce simple and reliable equipment for this purpose.

In the heating of steel, and more particularly in the heating of thin sections, such as sheets, scale formation acts as a very excellent guide in the judging of furnace atmosphere. Expensive equipment, such as CO_2 and CO indicators, is considered superfluous, because the surface of each sheet leaving the furnace serves as an indication of the furnace atmosphere.

Powdered coal presents a difficulty which does not exist with gaseous fuels, and exists only in a moderate degree with liquid fuel, namely, the necessity of complete combustion, or at least gasification, in the combustion chamber. Partly burned particles of coke can, as a rule, not be allowed to drop on the heating stock. In consequence, the combustion chamber must be long enough to burn them to CO_2, or to CO, if a reducing atmosphere is desired. But the combustion of the coke particles in a deficiency of air requires more time than it does in an excess of air. For that reason, combustion chambers for powdered coal must be made extra long, if a reducing atmosphere is to be maintained in the heating chamber. The time required for combustion of powdered coal, as given in Chapter II, may well be increased 75 to 100 per cent if a reducing atmosphere is desired. In a very long combustion chamber much carbon monoxide can be produced, and can be burned in the heating chamber with the characteristic blue flame.

Automatic Control of Furnace Pressure.—In the present chapter the statement has been made repeatedly that pressure should be maintained in the furnace and that its value should be kept constant. At the level of the hearth this pressure can only be very slightly in excess of that of the atmosphere. As a rule the excess is as small as a hundredth or a fiftieth of an inch of water. From the chart, Fig. 223, Volume I, one can read the velocity with which flame and hot gases would issue from the doors, or from observation holes and through cracks in the brickwork, if the pressure were in excess of that amount. On account of the high velocity which even a small pressure imparts to a hot gas, the pressure cannot very well be greater than indicated by the above figures.

Furnace pressure is established as an equilibrium between the forces which move the gases into the furnace and the resistance

to their outflow. With varying rates of firing, the vent dampers (if such have been provided) must be adjusted, if the furnace pressure is to remain constant. While it would be desirable to maintain furnace pressure automatically, it is, at the present time, regulated by the heater, who relies upon his eye for guidance and adjust the dampers so that a small " stinger," or wisp of flame, comes from the openings in the doors. The size of the stinger indicates the furnace pressure. In boiler work, systems for maintaining practically atmospheric pressure above the grate are in use. The devices which have been moderately successful in boiler work have not met with the same success in heating furnace practice. One reason is probably the mode of operation of industrial furnaces, which must frequently work with the doors partly open. At such times the pressure must necessarily be atmospheric. The pressure-regulating device then operates to maintain pressure, closing the dampers tightly, and forcing all the products of combustion out of the door or doors, into the faces of the workmen.

Furnace Atmosphere in Electrically Heated Furnaces.—In electrically heated furnaces the question of furnace atmosphere has not yet become acute. Such furnaces are, as a rule, used for comparatively low temperatures, that is to say, for temperatures below 1600° F. While scaling occurs at these temperatures, it is not excessive. For that reason, electrically heated furnaces are usually so constructed that there is practically no flow of air into the furnace or circulation of air through it. The whole furnace is enclosed in sheet steel, and all possible precautions are taken to have a very tight-fitting door. Whatever oxygen happens to be in the furnace at the beginning of the heating operation is soon used up, and practically no new oxygen is allowed to enter, except a little bit which leaks in by virtue of the slight vacuum produced by absorption of the oxygen by the steel. In any event, the total amount is limited. Observation holes are seldom opened, particularly if automatic temperature control is used; for that reason very little oxygen enters from that source. In annealing and heat-treating operations the parts which are sent to the electrical furnace have frequently been machined, and still have enough of an oil film on them to prevent serious oxidation. Before the steel is hot enough to form scale the oil vaporizes and burns in the furnace, absorbing the oxygen. The rest of the oil vapor

breaks up into its elements, forming a reducing atmosphere which protects the steel. If the parts are not oily a very small amount of oil sprayed over them, or on the trays containing the parts, has the same effect. Finely powdered charcoal is occasionally used for the same purpose. Illuminating gas or purified water gas is occasionally burned at the doors of continuous furnaces with electrical heat, for the purpose of keeping air away from the heating chamber. In this manner a reducing atmosphere can be maintained. An oxidizing atmosphere, if such were desired, could of course be maintained by allowing some air to circulate through the furnace all the time.

Muffle Furnaces.—A very popular means of protecting the charge from furnace gases and of heating it in the desired kind of

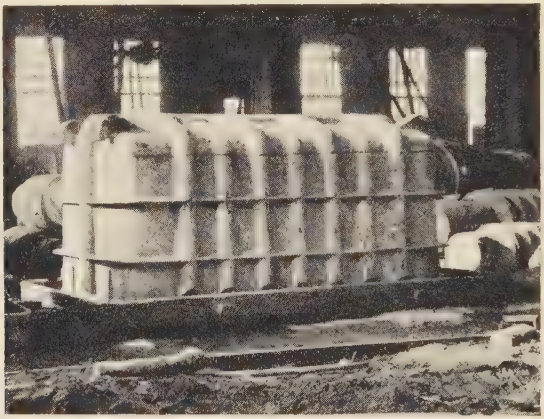

Fig. 176.—Annealing box, as example of a metallic muffle.

atmosphere is the muffle. Muffle furnaces are shown in Figs. 11 and 40, Volume I. A removable muffle is shown in Fig. 176; it is used in the annealing of sheets and of tin-plate and is commonly referred to as an annealing box. The atmosphere in a muffle is very similar to that in an electric furnace, and the same means are used for producing a reducing atmosphere. In particular, fine charcoal powder is frequently put into annealing boxes for that purpose. It serves not only during the heating period, but also during the cooling period, when the volume of the gases in the box shrinks, and air enters. Unfortunately, most muffles are permeable to gases at high temperature.

Bright Annealing of Iron and Steel.—Illuminating gas has been used for producing a non-oxidizing atmosphere. A continuous annealing furnace utilizing this principle is shown in Fig. 177. The heating stock enters on a conveyor, moves up and down through the muffle (which is heated by producer gas) and is discharged under water. Illuminating gas enters the muffle continuously, and is discharged through a burner at the cold end. As long as there is a flame at the burner, there is no danger of an explosion.

Bright annealing of iron or steel by electric heat has been brought to a high state of perfection by a German firm. The

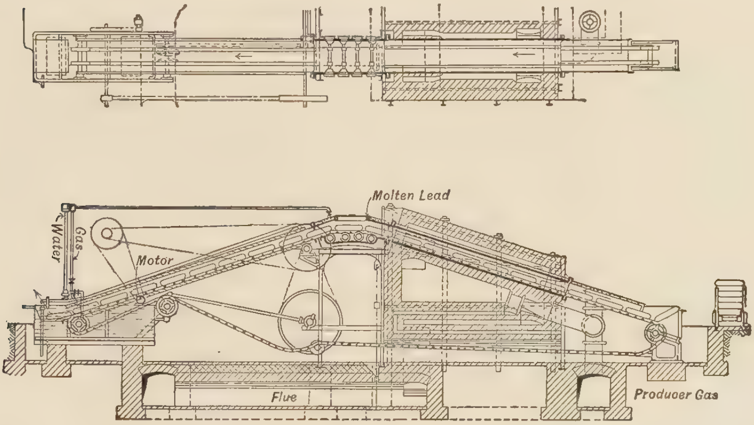

Fig. 177.—Bright annealing furnace. The muffle is filled with illuminating gas which enters at the left and is discharged through a small burner at the right.

principle is that of providing, in the furnace, an absolutely inert atmosphere, either by the introduction of nitrogen or hydrogen, or else by evacuation. Figure 178 illustrates a furnace for the use of an inert gas. The whole furnace rests on a pan or saucer, which is provided with an oil seal. A metallic hood, covering the furnace, dips into the oil, which is cooled by a water coil. When the charge is in place, carbon dioxide is admitted through the top until all the air has been displaced through the top. Hydrogen, or a similar gas, is then admitted through the top, until all the carbon dioxide has been displaced through the bottom. As a rule, two or three furnaces are provided, and the gases are

shunted from one furnace to the next one, whereby a considerable saving in gases is effected. When the furnace has been filled with inert gas, electric current is sent through the resistors, which are

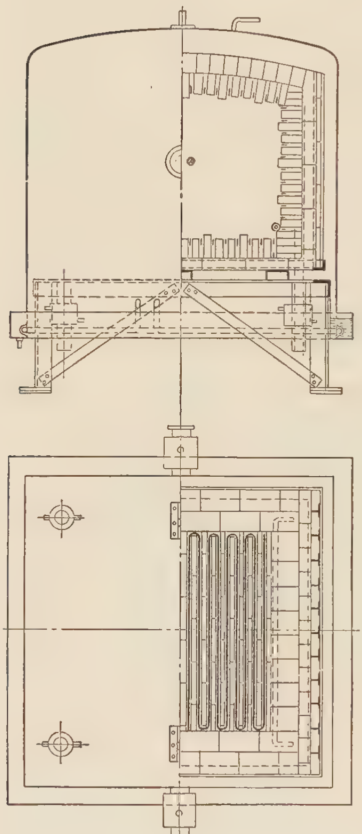

FIG. 178.—Electrically heated bright annealing furnace filled with an inert gas.

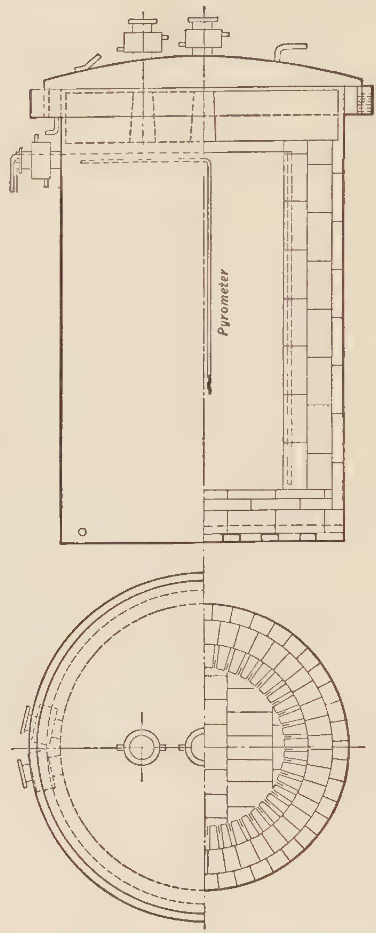

FIG. 179.—Electrically heated bright annealing furnace of the pit type, designed for complete evacuation.

of iron. Expensive alloys are not necessary. Iron has a very high temperature coefficient; for that reason, the resistors, if properly proportioned, will come up to the right temperature, and will not exceed it, even if no automatic temperature-control

equipment is provided. When the furnace is cold, a lower transformer voltage is used, so as to prevent a rush of current.

Complete evacuation serves the same purpose as an inert gas. If the charge is heated *in vacuo* the cost of the inert gas is replaced by the power consumption of the air pump. Besides, the furnace must be enclosed in a cylindrical shell which is strong enough to resist atmospheric pressure and, finally, the joint between shell and cover must be made air-tight. Charging and emptying the furnace requires time and care in the case of the vacuum process. Figure 179 illustrates a pit furnace suitable for evacuation.

Bright Annealing of Non-ferrous Metals.—Although steam (water vapor) furnishes an oxidizing atmosphere if steel is the material being heated, it produces a neutral non-oxidizing atmosphere for many other metals, such as brass, copper, silver, German silver, and similar materials. This fact is utilized, to a very large extent, in the practice of industrial furnaces. It is the underlying principle in furnaces of the muffle type, which the charge enters through water and leaves through water. A furnace of the batch type embodying this idea is shown in Fig. 180. This furnace and similar types are commonly known as bright annealing furnaces. From the illustration it is evident that the material is run on to a deck carried by a plunger, is dropped under water, moved under the muffle, and then lifted into the muffle. The bottom of the muffle is always under water, and its interior is always filled with water vapor. The water level must, of course, be sufficiently far below the hot zone to avoid serious heat losses. A furnace of this type for smaller work is illustrated in Fig. 181. The mechanism for lowering the charge under water, for rotating it until it is directly under the muffle, and for raising it into the muffle, is plainly shown and needs no comment.

The same principle has been used for the bright annealing of copper wire, brass wire, copper strips, and similar goods. In such furnaces the material enters in an endless strip under water, passes through the muffle, and is again discharged under water. The principle is very clearly indicated in Fig. 5 of Volume I. Heating processes in which the charge enters under water and leaves under water necessitate the use of very clean water, free from grease or scum, if the finish of the ultimate product is an important factor.

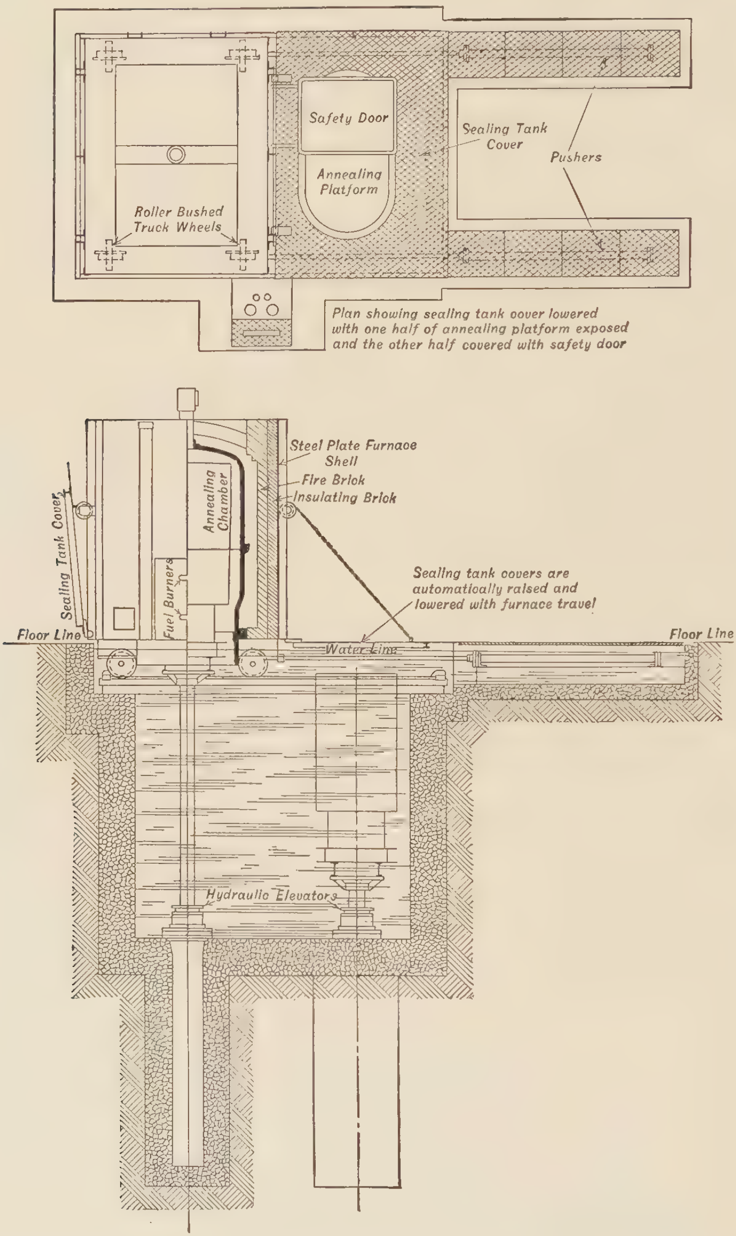

Fig. 180.—Car-type non-oxidizing annealing furnace for non-ferrous metals.

Japanning Furnaces or Ovens.—" Japanning " means dipping in a lacquer and drying the latter on the product. The drying consists in an evaporation of the solvent and in a chemical change in the lacquer. Depending upon the solvent, a more or less

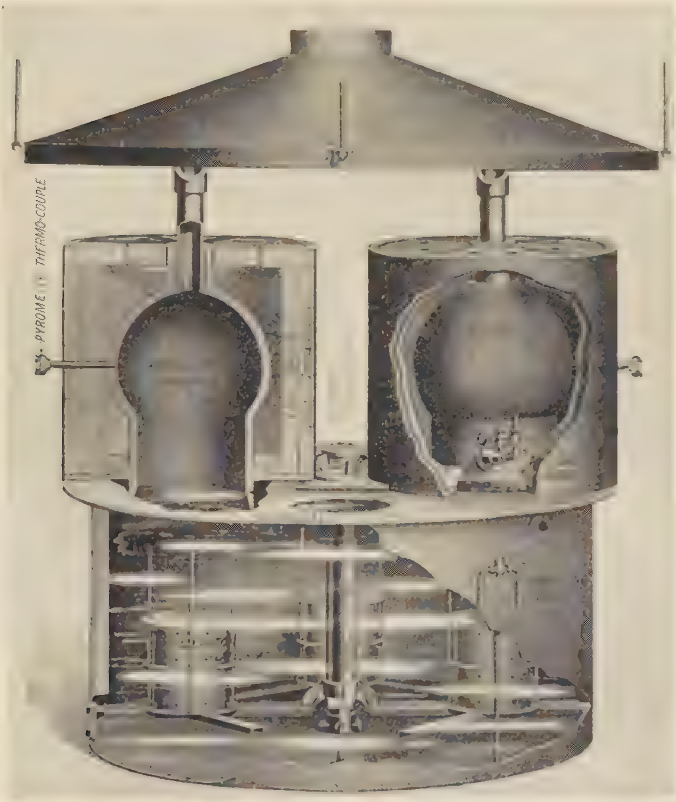

FIG. 181. Bright annealing furnace. Heating takes place in an atmosphere of superheated steam.

Note the steam vent at the top of each annealing chamber.

explosive mixture is formed by the heated vapor of the solvent and the air. To prevent explosions, the air must be changed frequently enough to dilute the vapor-and-air mixture and to keep it below the explosion point. Whenever that point is accidentally passed the mixture is ignited, and an explosion occurs. Explosions in japanning ovens may be serious, and have killed people.

For that reason, japanning ovens are usually equipped with very light, quick-opening explosion doors.

Carburizing Atmosphere.—If iron or steel is heated to about 1700° F. in an atmosphere of hydrocarbons, such as natural gas or retort gas, carbon is liberated and combines with the iron or steel, putting a "case" on the pieces being thus treated. Very complete machines are on the market for carburizing iron and steel by the gas method.

CHAPTER V

LABOR-SAVING APPLIANCES

Classification of Labor-saving Devices.—In the cost of industrial heating the item of labor occupies a major position. Comparatively speaking, fuel is cheap and labor is dear. While this statement may not be true in some countries, it certainly holds in the United States; it is, therefore, only natural that many labor-saving devices should be introduced in this country in connection with furnace work. Such labor-saving appliances fall into three classes.

One class of devices serves for saving labor in the generation and application ot heat. The appliances of this class may be subdivided into (*a*) those which automatically deliver fuel to and into the furnace, and (*b*) those which automatically maintain constant temperature and atmosphere in the furnace. A second class consists of those materials and designs which reduce furnace maintenance and repairs, while a third class embraces those appliances which reduce the labor of charging, transporting, and discharging the material to be heated. The characteristic features of the first-named class, the devices used for saving labor in the generation and application of heat, are briefly described in Chapter I on "Fuels" and in Chapter II on "Combustion Devices." Additional information on this topic is contained in Chapter VI. The second class of labor-saving equipment is intended to increase the strength and durability of furnaces, both of which were discussed in Volume I. It is the third class, namely, labor-saving devices used in connection with the charging, transporting, and discharging of the material to be heated, which forms the topic of the present chapter. An additional class consists of that equipment which, although not strictly labor-saving, is closely allied with the equipment under discussion, as it serves to make work around furnaces comfortable and increases the work done per man in unit time.

Devices for saving labor in the handling of materials form two broad classes, depending very largely upon the type of furnace which they serve. One class is used for charging and emptying batch-type furnaces, whereas the second class consists of equipment for delivering the stock to a continuous furnace and for moving it through the latter.

Labor-saving Equipment for Batch-type Furnaces.—The devices for moving material into and out of batch-type furnaces cover a wide range. They include simple containers, such as pots, pans, and trays, as well as complicated charging machines.

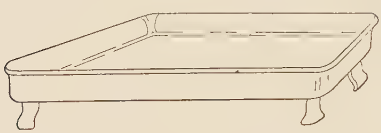

Fig. 182.—Tray container.

Pans and trays for containing piled material are in very common use, not only for very small articles but also for pieces as large as couplers for railroad cars. A typical pan has been sketched in Fig. 182. It will be noted that it has short legs, which serve two purposes: first, they allow the fork of the lifting lever or charging machine to enter between the hearth and the tray itself; second, they elevate the charge above the floor and allow circulation of the furnace gases under the tray.

It is evident that any heat which is imparted to the tray is lost, unless a tray can be dumped and immediately charged again before it has become cold. Since the latter method is very seldom used, the heat in the tray is, as a rule, lost. For that reason trays should be made just as light as is consistent with strength and rigidity. It is desirable to have them made of a non-corrosive alloy (containing iron and chromium, or iron, chromium and nickel), because trays made of such material last very much longer than those made of cast iron or steel, and can, for that reason, be made lighter. Furthermore, alloys do not drop any scale on the floor of the furnace. Closed pots and boxes do not properly come under the heading of labor-saving devices, because they serve principally as muffles, or as containers, not only for the charge but also for some other material, such as a hardening compound.

Pans, pots, or trays are usually moved in and out of the furnace by means of lifting forks equipped with wheels. A sketch of such a lifting fork is given in Fig. 183. Many modifications of the lifting fork are in common use; they depend upon the size,

height, and design of the furnace, and upon the shape of the container to be lifted. If the furnace hearth is near the floor of the building, the handle of the lifting fork is bent upward. If the hearth is elevated, the handle of the fork has the shape shown in Fig. 183.

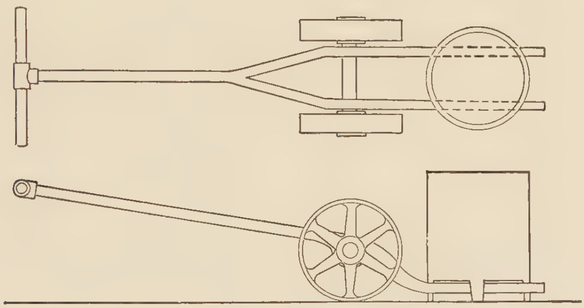

FIG. 183.—Wheeled lifting fork.

When individual pieces, not resting in a container, are heated in a furnace, the handling is done with tongs if the individual pieces do not weigh more than 40 or 50 pounds. Heavier bars or pieces up to 400 or 500 pounds are handled with tongs, or with peels which are suspended from a monorail. Still heavier blooms

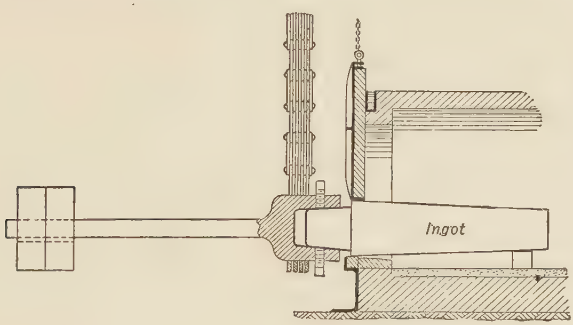

FIG. 184.—Porter bar suspended from crane.

or slabs are handled by tongs suspended from cranes, or else by means of manipulators or charging machines. Heavy bars or forging ingots are frequently handled by means of porter bars which are suspended from cranes, as illustrated in Fig. 184. Heavy ingots hanging from porter bars must be handled very

slowly and with extreme care, because the sudden stopping of a crane which carries a fast-moving ingot at the end of a porter bar produces a long forward swing. Altogether too often the ingot strikes the furnace walls or the door jambs, or else the chain strikes the top of the door, and the bricklayers are kept busy. In some forge shops the repair bills have been reduced by the installation of projecting aprons just above the furnace doors. While these aprons save the furnace, they are disliked by the heaters, because they do not allow the crane chains to come close to the furnace door. The porter bar shown in Fig. 184 remains

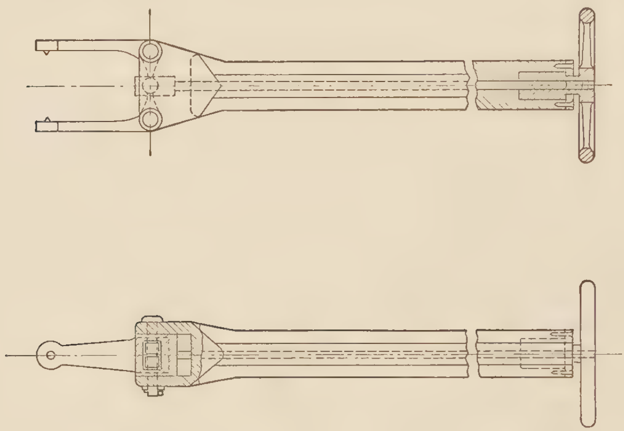

FIG. 185.—Tong-hold porter bar. Turning of the handwheel attaches the bar to the bloom, or disengages it.

attached to the ingot while the latter is in the furnace. With this arrangement, part of the ingot projects out of the furnace. If the whole ingot, or heavy bloom, is to be placed inside of the furnace, it is necessary to attach the porter bar to the bloom by means of tongs. A design serving this purpose is shown in Fig. 185. In depositing ingots in a furnace, furnace tenders often place a roller at the end of a handle bar (compare Fig. 186) under the ingot. The crane trolley is run to a position vertically above the furnace. By this motion, the crane chain, which supports the outer end of the ingot, becomes inclined and exerts a pull towards the furnace. In consequence, the ingot, rolling on the roller, slips into the furnace and is deposited with its rear end resting on a ledge in the furnace. The crane then lifts the front

end of the ingot, and the roller is withdrawn. Reference has already been made to the fact that any heavy mass suspended from a crane is hard to handle on account of the swinging. For that reason, manipulators and charging machines are very much better, although, of course, they are to be classed as special equipment and require an extra investment.

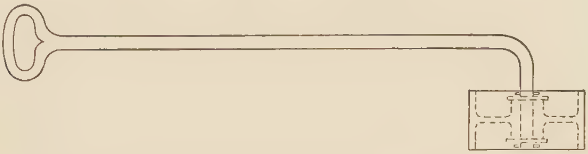

FIG. 186.—Roller for shoving blooms into the furnace.

Figure 187 illustrates a comparatively simple charging machine which has been converted from a general utility truck, and has been found to be very useful for quickness and convenience in charging and emptying batch-type furnaces. A smooth floor is

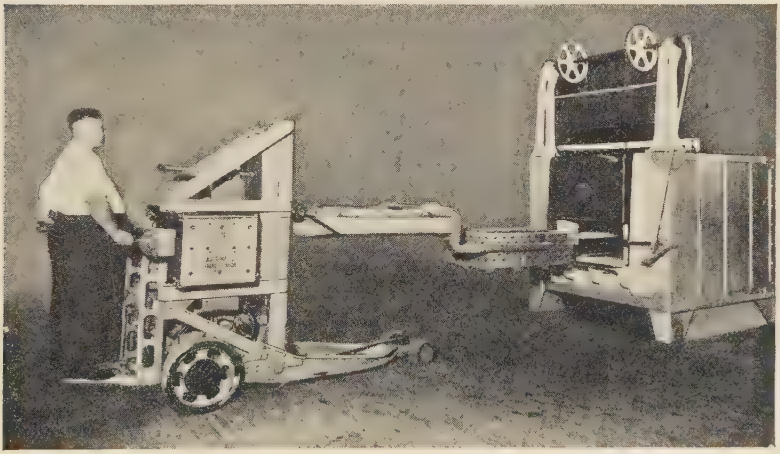

FIG. 187.—Simple furnace-charging machine.

a prerequisite for the use of this truck. For rapid work in connection with heating furnaces in rolling mills, or in high-speed hammer or press work, regular charging machines, as offered to the trade by several first-class firms, are in use. Figures 188 and 189 illustrate such machines. The machines here illustrated have

a swinging arm. They are more expensive than machines with a fixed arm, but they have the advantage of serving the hearth between the furnace doors. The grabbing and holding tongs of these charging machines have been given particular attention, because they are in the hot furnace a considerable part of the time. Water tanks are usually provided for cooling them if they are in danger of becoming overheated. A detailed description of these machines does not belong in the present volume. In the handling of heavy forgings, a "manipulator" serves both the furnace and the forging press. It is similar to a charging machine,

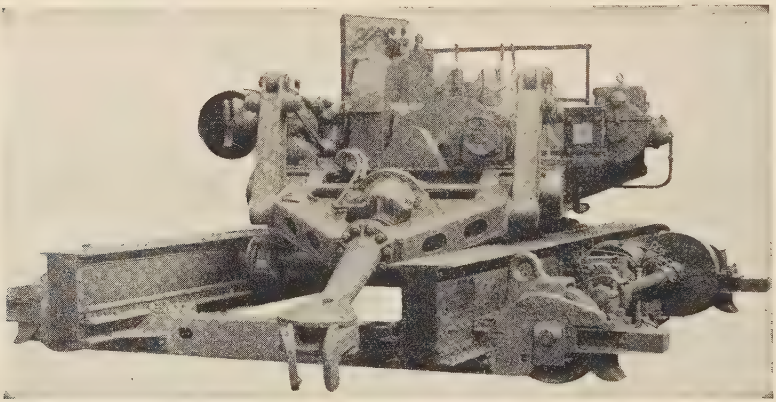

FIG. 188.—Electrically operated charging machine.

but is arranged to yield downwardly as the forging is compressed under the press.

Heavy material is very cumbersome to handle, even with charging machines. For that reason, furnaces for heavy and bulky material are frequently built with roofs which are removable.[1] The charge is then placed in the furnace, by means of a crane, after the roof has been removed from the furnace, is heated

[1] In the practice of melting malleable iron, removable roofs in short sections, similar to Fig. 190, are employed. They are called "bungs," bung-roofs, bung-top roofs, or bung-top arches. The same names are frequently applied to other removable roofs of furnaces.

The roof over the combustion chamber of a malleable-iron furnace burns out quickly. The other "bungs," which have been over the cooler part of the furnace, are then moved forward. This practice may well be imitated in certain reheating furnaces.

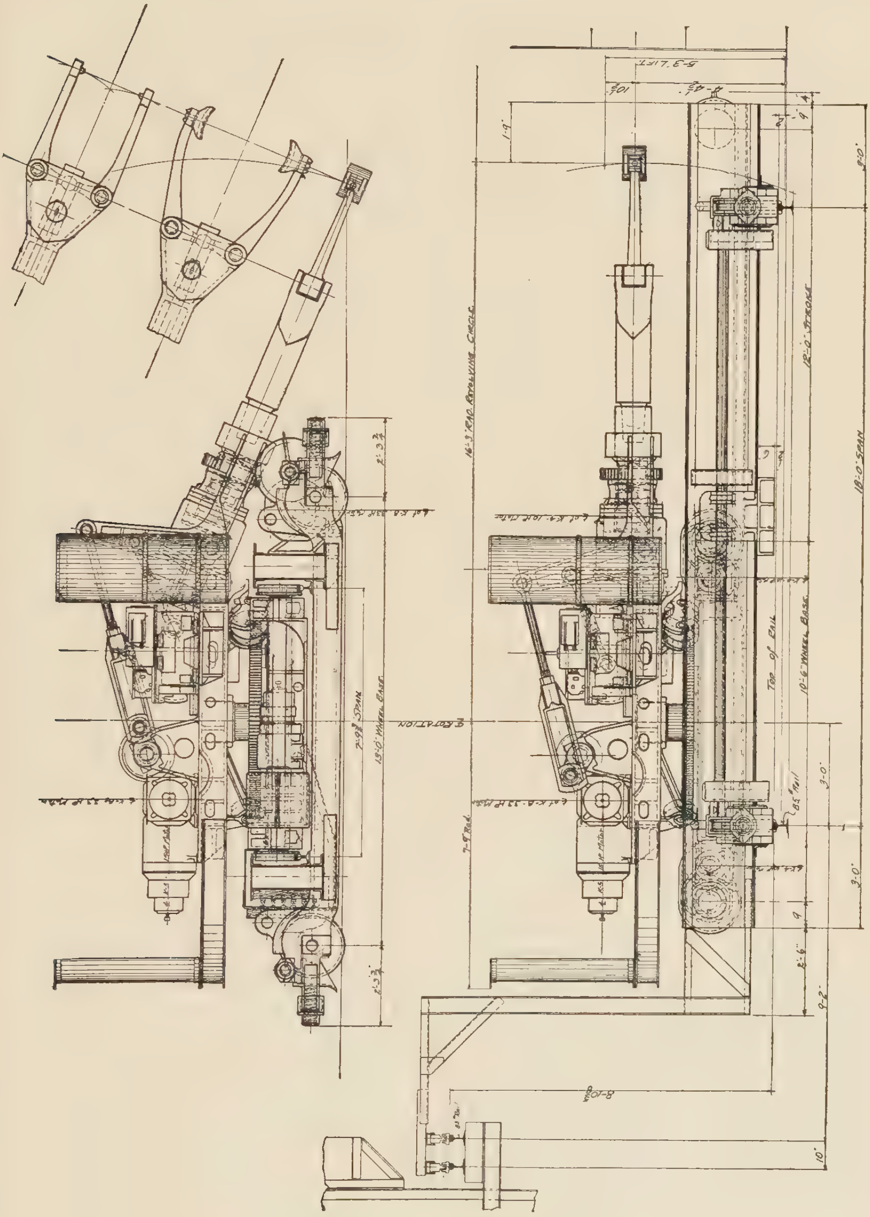

FIG. 189.—Plan and elevation of charging machine for furnaces.

with the roof in place on the furnace, and is finally taken out after the roof has again been lifted off. While such roofs might be considered as part of the furnace proper, they are, in reality, labor-saving devices, because they would not be used unless it were necessary to put bulky and heavy material into the furnace from the top. Figures 190, 191, and 192 are illustrations of removable roofs. In them, a metallic frame serves as an abutment. Since the frame and the refractory filling expand at dif-

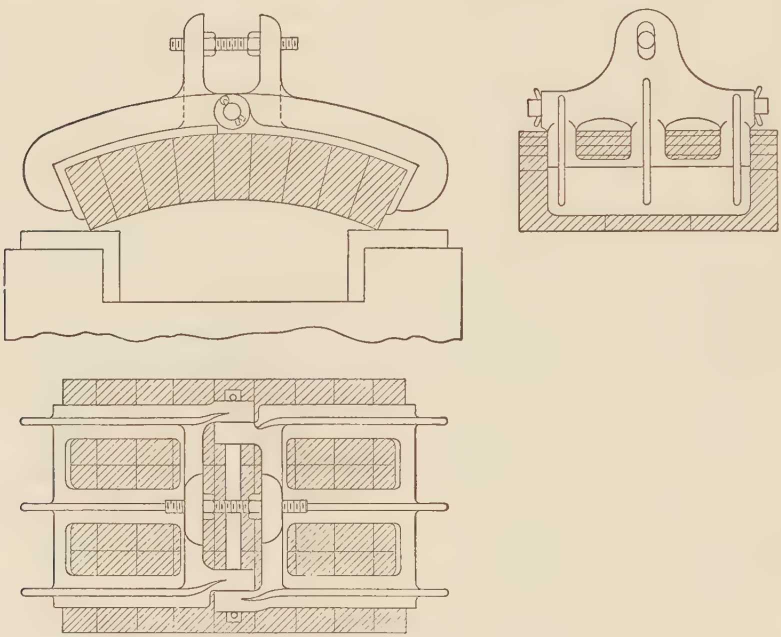

Fig. 190.—Adjustable furnace cover.

ferent rates, and since the frame can hardly be made strong enough to restrain the bricks from expanding, it must allow expansion by means of the rising of the arch, or else must be made of a ductile material which does not break when stretched. Furthermore, it must either have means for adjustment of the clamping of the bricks, or else the latter must be so selected that temperature changes do not cause expansion or contraction. In Fig. 148 of Volume I, it is shown that firebricks lose in volume above a certain temperature. The loosening effect of the shrinkage is

often accentuated by the fact that the expansion of the bricks below the critical temperature forces the metallic abutment apart.

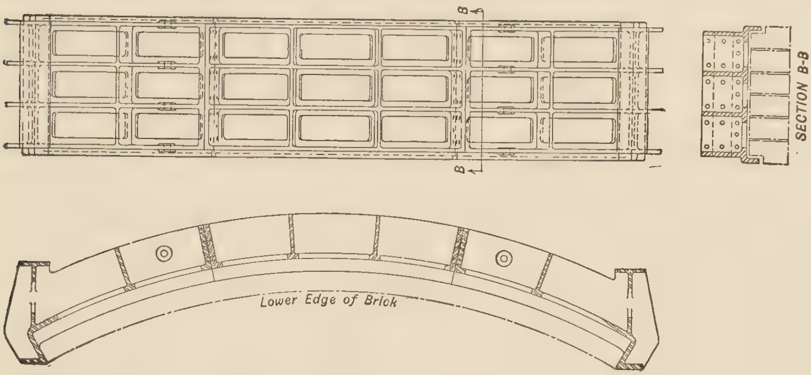

FIG. 191.—Section of removable roof for a large annealing pit.

From all of these causes, namely, the forcing apart of the metallic frame during expansion of the bricks, the shrinkage of the bricks

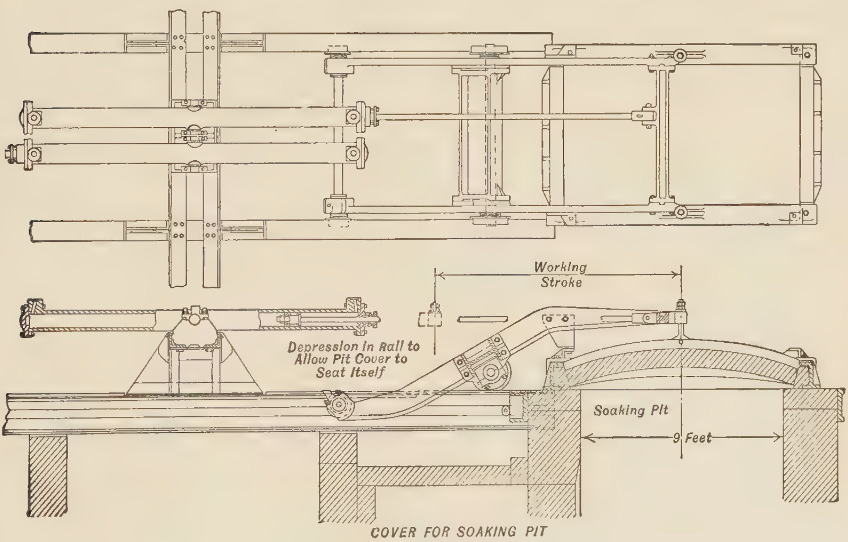

FIG. 192.—Cover for soaking pit.

at high temperatures, and their contraction at low temperatures, the refractory filling becomes loose and drops out unless counter-

acting measures are taken. Figure 190 represents a very common method of overcoming the difficulty. The frame holding the bricks is made of two sections, which are hinged and are provided with lugs. By means of the latter the two halves can be pulled together or pushed apart. In the illustration the screw connecting the two lugs, and used for adjustment, is very clearly shown, and no comment is needed.

The force which the framework of a loose cover has to withstand can be judged from the principles laid down in Volume I, on the design of roofs and arches, pages 196 and 238. The horizontal thrust (which can be computed from the arch weight and the multiplying factor given in Volume I) tends to bend the metallic frame, in addition to producing tension. To withstand these forces, the metal work of removable arches is built very substantially. A strongly built arch is shown in Fig. 191, which illustrates the section of a removable roof for a very large pit annealing furnace. This roof has several interesting features. It is so designed that the sections can be stacked on top of one another. It has the additional feature that overall expansion and contraction of the bricks is almost entirely eliminated by the alternations of four fireclay bricks with one silica brick. The heating and cooling of this roof is never rapid enough to injure the silica bricks.

Removable arches must, of course, be so designed that they can be lifted off with ease, for which purpose there are usually provided eye openings through which hooks of crane chains can enter. It is also advisable to remember that the stress distribution, when the arch is suspended from the crane, must not be such as to cause the metal work to take a permanent set or the bricks to become loose. It must finally be mentioned that there can be no permanent tie-rods over the tops of furnaces that have removable tops. The furnace itself must be bound in a horizontal plane, strongly enough to withstand expansion. For that reason large furnaces with removable roofs are very frequently built as pit furnaces.

Figure 192 illustrates the movable roof of a pit furnace of that type which is commonly referred to as a soaking pit. In this case the roof is moved very frequently, because pit furnaces receive hot steel, which requires heat equalization rather than actual heating. For this reason the steel stays in the pit a comparatively

short time. Soaking-pit covers are commonly so arranged so that they are moved upward a little bit before the horizontal motion starts. In Fig. 192 the upward movement at the start of the uncovering is accomplished by having the cover suspended from a lever which rests against a rail. The latter has a notch into which the roller drops in the closed position of the cover. The slightest horizontal displacement of the system causes an upward movement of the pit cover. On account of the frequency

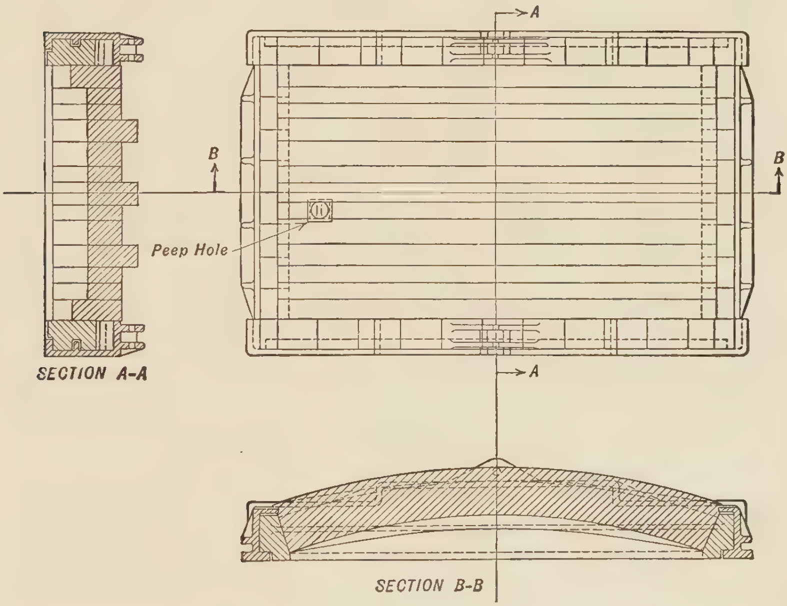

FIG. 193.—Method of laying bricks in cover of soaking pit.

of the opening and closing movements, soaking-pit covers must be made particularly strong and durable. The method of holding the bricks securely in place is shown in Fig. 193. Soaking-pit covers with cast iron poured around the bricks have given trouble.

If furnaces with removable tops are charged and emptied while the material and the furnace are comparatively cold, common cranes can be used. If hot material is charged into pit furnaces with removable roofs, or is taken from them, ordinary cranes are very unpleasant for the attendants, because the material tends to swing from the crane chain and must be kept from swinging by a

man standing alongside of the furnace and guiding the material by means of a rod with a hook. The heat radiated from the open pit to the attendant is so extreme that the guiding is frequently poor and the hot material bumps against the side of the furnace or against the roof, injuring it and knocking down the brickwork. For that reason furnaces are now served by stiff-legged cranes, so-called soaking-pit cranes, the working part of which is illustrated in Fig. 194.

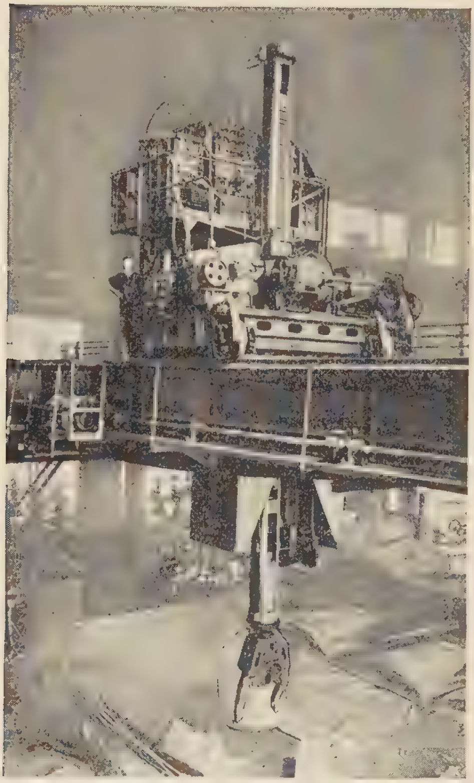

Fig. 194.—Stiff-legged crane for charging pit furnaces.

If long and heavy pieces are heated in pit furnaces, very tall buildings with expensive cranes are needed; besides, there is required a device for laying the pieces down and for attaching a porter bar to them or enabling the manipulator to take hold of them. For that reason long and heavy pieces are frequently heated and annealed in car-type furnaces. From the thermal standpoint, that is to say, with regard to uniformity of heating, the ordinary car-bottom furnace has no advantages to offer. Its reason for existence lies solely in the advantages which it has with regard to the mechanical handling of the material. A car-bottom furnace is illustrated in Fig. 195.

The car-type furnace has certain disadvantages. If the car is pulled out of a hot furnace, the radiation from the latter is directed towards the floor. This floor must not be made of bare

concrete, but must be covered with firebricks, because otherwise it would be cracked to pieces. Pulling the car out of the hot furnace means a great heat loss, which, however, might have to be incurred anyway, when the furnace is cooled off in order to make it ready for the next charge. In combustion-type furnaces it is usually difficult to get the car bottom as hot as the top of the furnace, and cold spots are likely to result, unless the charge is elevated from the floor on stilts or supports, and the gases are forced to circulate energetically between the floor and the charge. In some cases it has been found necessary to put auxiliary burners near the floor of the car for the purpose of injecting hot gases

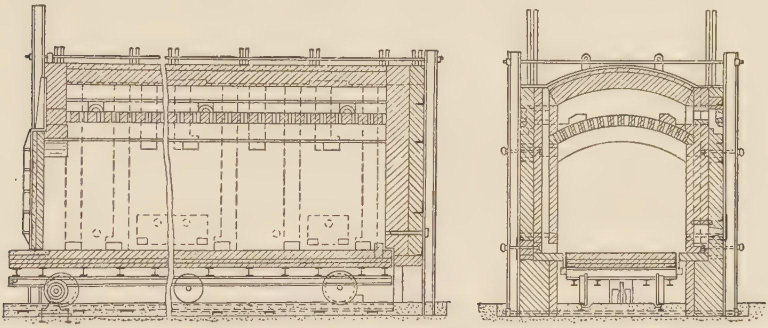

FIG. 195.—Car-type furnace.

between the car bottom and the charge. Such burners are indicated in Fig. 195. In order to prevent heat losses it is customary to place insulating material between the firebricks of the car and the steel work upon which it rests. If material is to be piled directly on the car, the hearth is made of vitrified brick, which withstands abrasion better than ordinary firebrick.

All car-type furnaces must have a seal for preventing free circulation of the gases between the space underneath the car and the heating chamber. In a few cases water seals have been used; but by far the greatest number of car-type furnaces are provided with a sand seal, because water interferes with endwise movement of the car, and also because it evaporates. A seal which has given very good results is shown in Fig. 196. On account of the moving of the car in and out of the furnace the sand has a tendency to distribute itself irregularly and to pile up at one end or the other. In most cases the angle iron which forms the seal in

the sand is fastened rigidly to the car. In the illustration shown it can adjust itself up and dòwn to a certain extent, whereby greater safety against leakage of gases is secured. The sand seal should be so located that neither the sand-holding trough nor the blade will be damaged when the car is out of the furnace. In a few cases very fine silocel powder has been found to be more advantageous than sand.

The moving of heavy cars involves time and hard labor if it is to be done by hand. For that reason cars are usually moved in and out of furnaces by what is commonly known as a car puller. A car puller is diagrammatically shown in Fig. 197. It consists simply of an electric motor working through a set of speed-reducing gearing and winding a cable or a chain in one direction or the other. The car is hooked to one end or the other of the chain or the cable and is thereby moved into the furnace or out of it.

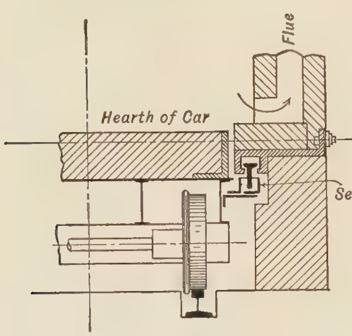

FIG. 196.—Sand seal for car-type furnace.

Furnace cars travel either on wheels or on balls. Cars resting on wheels are usually equipped with roller bearings. The latter must be strong enough to withstand a temperature of 500° to 550° F. It is one of the tasks of the designer to arrange for just sufficient ventilation under the car, so that there will be neither overheating of the bearings nor serious heat losses through the hearth of the car. It is desirable to have all the wheels running on one rail equipped with two flanges, and to have no flanges on the wheels which run on the other rail. In the hot furnace the car expands, and if there were flanges on the wheels running on both rails they might grip and bind. If the car is moved into the furnace on balls, as is illustrated in Fig. 198, there should be a long runout for the balls, because they move at only half the speed of the car, and, in consequence, move only half the distance. Careful spacing of the balls is a necessity. Resting the car on balls is, of course, much cheaper than mounting it on wheels; but the balls and their V-shaped track take up room even when the car is

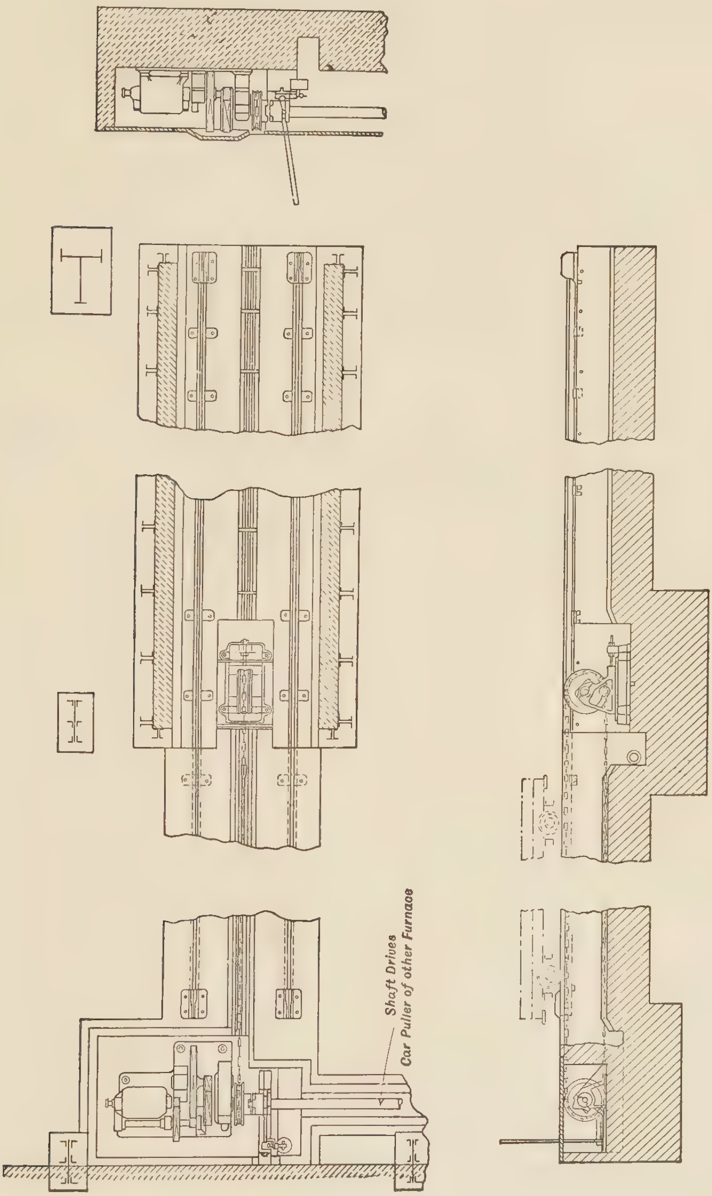

FIG. 197.—Electrically driven car puller.

Note reversible motor with triple gear reduction. Chain pulley is connected to drive shaft by jaw clutch.

in the furnace, and therefore are not liked by some engineers. Attempts have been made to improve the situation by providing run-outs for the balls at both ends of the furnace, or by providing an inclined return for the surplus balls.

For special purposes car bottoms are specially equipped. For the enameling of ceramic materials, for instance, they are provided with prongs, which rest on points only. For material which is to be heated almost to a welding heat (given a "wash-heat")

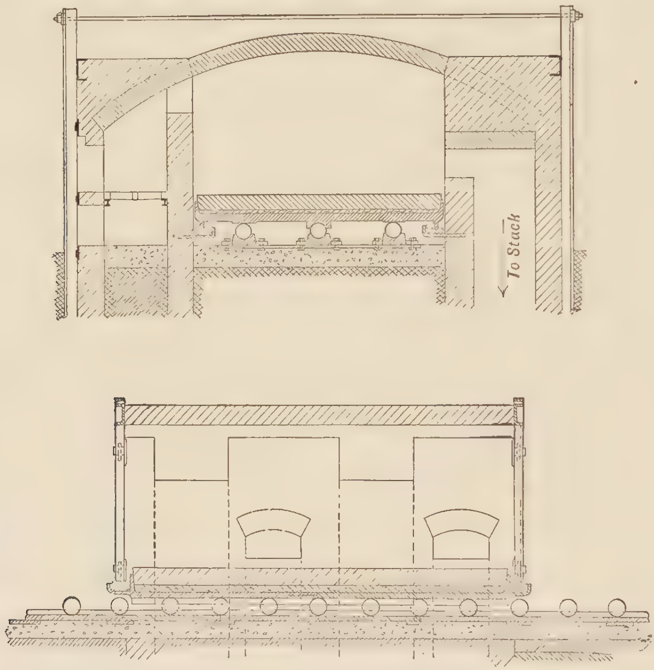

FIG. 198.—Car and ball furnace.

the cars are equipped with slag holes towards which the floor slopes. Such a car is illustrated in Fig. 199. It is evident that cars with all sorts of special hearths can be designed to take care of the manifold requirements of industrial heating.

It may be mentioned that cars are used also for the purpose of moving material continuously, or more or less continuously, through a furnace. The type of car used for that purpose will be considered later on under "Continuous Furnaces."

A device used for charging containers filled with packs of thin sheets into batch-type annealing furnaces is the goose-neck charger, shown in Fig. 200. This is simply a C-shaped section, usually made of structural shapes, suspended from an overhead traveling crane, and having an extended lower leg which is run under the annealing box to lift it and insert it in the furnace. The proportions and weight of the back of the C must be such as to balance the weight of the box. With this device, vertical lifting furnace doors would cause interference; hence the doors are either of the swinging type or are arranged to drop down into a depression below the floor.

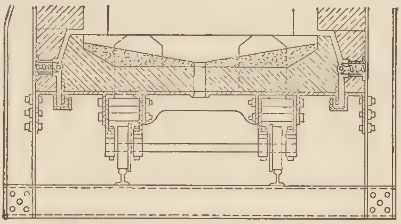

FIG. 199.—Furnace car arranged for slag removal.

Labor-saving Equipment for Continuous Furnaces.—Whenever the conditions are such that continuous transportation of the material through a furnace is possible, that method of transportation is adopted, because it effects a saving of labor far beyond that which can be achieved by any other method. It is quite evident that the use of continuous furnaces is predicated upon a fairly continuous production, because continuous furnaces, that is to say, furnaces through which the material moves continuously, are not adapted to intermittent operation.

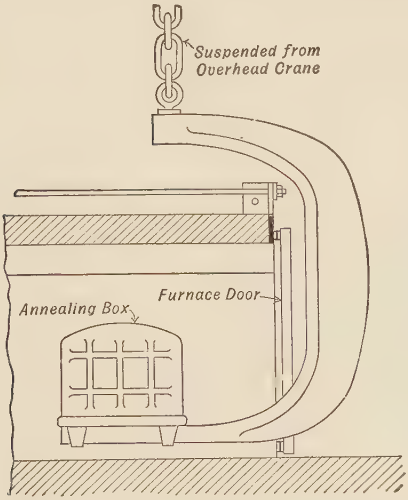

FIG. 200.—"Goose neck" charger.

In the present chapter only the labor-saving features of continuous furnaces are dealt with. The fuel-saving features are analyzed in Chapter IV of Volume I. The method of moving material through a furnace varies greatly with the temperature of the furnace, with the shape of the material to

be conveyed, and with the size of the individual pieces to be handled.

It may be justly stated that, in the invention and design of continuous furnaces, the inventive genius displayed by Americans in the field of mechanical engineering has shown itself ready to meet any demand. Given a sufficiently large demand for heating quantities of rather uniform shapes of material, a continuous furnace for doing the work is invariably developed. So insistent is the demand for mechanical conveying of material through furnaces that considerations belonging strictly to mechanical engineering frequently overshadow those of combustion engineering or heat engineering in the drawing rooms and shops of modern furnace builders.

The following classification gives an idea of the great variety of continuous furnaces:

(*A*) Straight-line motion.

- (*a*) Pusher.
  - (1) Direct.
  - (2) Indirect (trays or containers).
- (*b*) Roll-over.
- (*c*) Conveyor.
  - (1) Chain.
  - (2) Belt.
  - (3) Rollers.
  - (4) Moving cars.
  - (5) Monorail for partial heating.
  - (6) Special-purpose conveyor.
  - (7) Material its own conveyor.
  - (8) Shaker hearth.
- (*d*) Rocker bar (walking beam).
- (*e*) Vertical type.

(*B*) Circular motion.

- (*a*) Rotating hearth (doughnut type).
  - (1) Outside charge, internal delivery.
  - (2) Outside charge, outside delivery.
- (*b*) Stationary hearth, moving furnace.
- (*c*) Other circular conveyors.

(*C*) Helical motion.
- (*a*) Smooth drum.
- (*b*) Ribbed drum.

Straight-line Motion; Pusher-type Furnaces.—A very popular and effective method of moving the material through a furnace consists in pushing it over a hearth. Furnaces operated in this manner are known as " pusher "-type furnaces. Several features concerning the hearth construction of these furnaces are dealt with in Volume I, under the heading of " Strength of Hearth." If steel is to be heated to rolling or forging temperatures, the pusher type of furnace is the only practicable continuous furnace with straight-line motion, because no materials known at the present time will withstand the temperatures and the action of slag in other types of continuous furnaces.

The furnace type under discussion is built either with end discharge or with side discharge. The end discharge, or gravity discharge, type is preferred whenever it can be used, because several furnaces equipped with end discharge can be placed side by side and can discharge the heated material on a conveyor. The total furnace capacity can be increased by the addition of more furnaces as the demand for heated material grows. Furnaces of the side-discharge type must be used when long bars of comparatively small cross-section have to be heated for rolling in continuous mills. In order to avoid excessive speeds at the finishing pass such bars must enter the first stands of the mill very slowly. A long heated bar would become very cold at the rear end if it were lying on a guide or a roller table. For that reason the rear end of the bar must be kept in the furnace while the bar is going through the first slow-speed passes of the continuous mill. The capacity of these furnaces is strictly limited. When the mill rolls heavy sections, a great deal of steel must be heated in pounds per square foot of hearth and hour. When the mill rolls very light sections, the amount of steel to be heated in the furnace in unit time is comparatively small. The result is that the furnaces are designed for an average section, and that whenever heavy sections are rolled, the furnace capacity is insufficient. In that case the furnace is forced, and furnace repairs run up considerably. It is possible to bring preheated bars into the furnace, but that method of increasing the capacity does

away with the labor-saving features which are so highly prized in continuous furnace practice.

Continuous furnaces must be equipped with trouble doors. The material which is pushed through the furnace is not always uniform, and is not always made with sufficiently square edges to assure uniform pushing.

Material with round edges, or pieces of a very crooked shape (for instance, sheared billets), will occasionally "climb up"; that is to say, one piece will come to lie on top of another, or several pieces may pile up, one on top of the other. For this

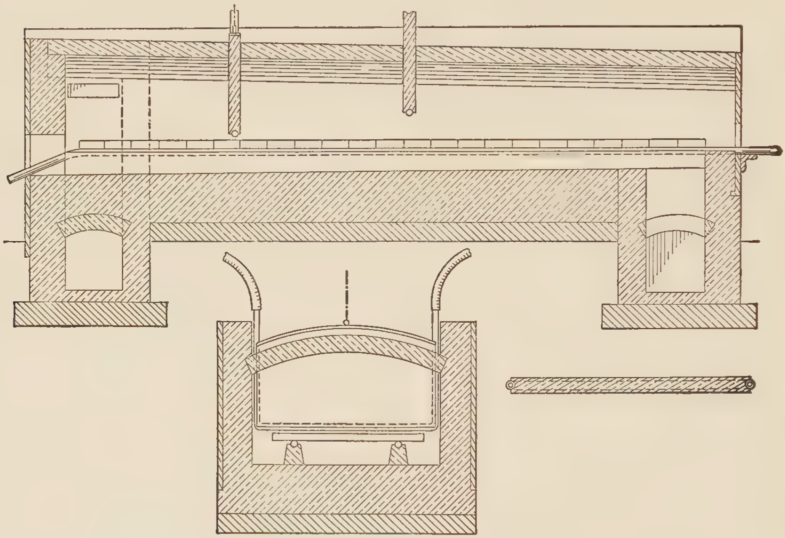

FIG. 201.—Continuous furnace with movable curtain walls.

reason continuous furnaces are frequently built with rather high roofs, in which case the large space between the top of the stock and the roof has a bad effect upon the fuel economy of the furnace. The products of combustion, instead of giving up their heat to the material being heated, travel along the roof and pass out without giving up a sufficient amount of heat. In those furnaces in which "climbing up" of the steel is not to be anticipated the roof can be lowered, or else a water-cooled pipe can be put across the furnace, for carrying a brick curtain wall. A furnace embodying this feature as shown in Fig. 94, on page 128 of Volume I. It has even been suggested that the partitions for holding the gases down

be so constructed as to be capable of vertical movement. Such a construction is shown in Fig. 201. It is doubtful, however, whether it is practicable. It would cause trouble in maintenance; climbing steel would wreck a movable curtain just as easily as a fixed curtain.

The thinner the material which is to be pushed through a furnace, the greater is the possibility of the pieces piling up and climbing on top of one another. For long furnaces, the lower limit of thickness is generally considered to be $1\frac{3}{4}$ inches. For handling slabs or rods of less than $1\frac{3}{4}$-inch thickness, furnaces have been built in which the skid pipes are made concave, for the purpose of having the pusher force exert a downward component

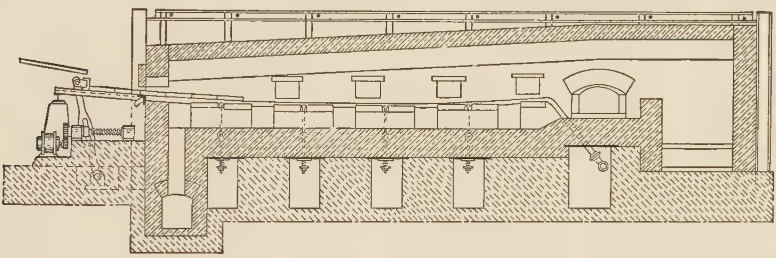

FIG. 202.—Continuous furnace with concave skid pipes.

towards the skid pipes. Unless the irregularities are extreme, this arrrangement has a tendency to keep the stock in contact with the skid pipes. Such a design is shown in Fig. 202. Plates and sheets cannot be moved through continuous furnaces by means of pushers.

At the other extreme of the range of material sizes we come to the difficulties arising in pusher-type furnaces that are used to heat heavy sections. Some of these difficulties were mentioned in Volume I. The principal difficulty is that of combining a satisfactory pushing apparatus with the arrangements for obtaining a uniform temperature throughout the heavy ingot, bloom, or slab. A number of patents have been taken out for devices intended to turn ingots over, so that the latter will, at the soaking end of the furnace, expose their cold sides (including black spots) to the heat, and thereby become more uniformly heated throughout. On account of the cost of maintaining these schemes, very few of them have survived. One of the simplest and most successful turn-over

devices originated in the Pacific Northwest of the United States and is shown in Fig. 203. By means of this device it is possible to give the ingot either a quarter turn or a half turn. From Fig. 203 it is plain that a bar, which is rigidly held and yet quickly adjustable, can be slid into the furnace and placed against the ingot in such a manner that it will either push the ingot along or turn it over, depending upon the elevation of the bar. As soon as compressed air is turned into the power cylinder the ingot will be turned over if the bar touches the side of the ingot near its top; while the action is that of a pusher only, if the bar rests against the bottom of the ingot. The slide or cross-head which holds the bar is guided by a rail and is equipped with a U-shaped wearing piece, which can be replaced after wear has occurred. A small stream of water runs on to the end of the bar in its normal position, at rest outside of the furnace, so that the bar will not become overheated by repeated use in the hot furnace.

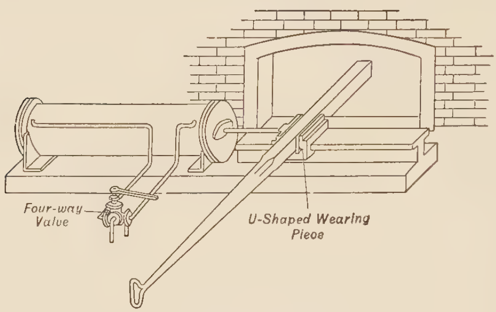

FIG. 203.—Ingot manipulator.

In order to make the pusher and turn-over device (Fig. 203) effective the ingots or blooms must evidently be separated by some other means before the turn-over bar can enter. The initial separation can be effected in several ways. A sudden increase in the downward slope of the skid pipes separates the ingots or slabs at the top. Pushing the steel off the end of the skid pipes is another effective method. Ingots and blooms of moderate size, say, up to 8 inches diameter (or length of side), can be allowed to drop over the edge of the water-cooled pipe skids, on to the brick fore-hearth, as indicated diagrammatically in Fig. 204. When heavy ingots, say, up to 23 inches diameter (ingots of 23 inches short diameter of octagon have been pushed over pipe skids), are pushed through a continuous furnace, they are, as a rule, not dropped on to the fore-hearth as indicated in Fig. 204, on account of the damage which they would do to a soft,

slaggy hearth, and because they could never be heated with any degree of uniformity on a ventilated or water-cooled hearth. However, the hearth may be cooled where the ingot drops down, and the ingot may then be pushed or rolled over by a device such as the one shown in Fig. 203. If this is not done, the ingot may be caused to turn over by giving the skid pipes a peculiar shape such as shown in Fig. 205; or else the ingot may be pushed on to the fore-hearth without being turned over automatically, and can then be moved around and turned over by a manipulator, such as the one illustrated in Figs. 188 and 189.

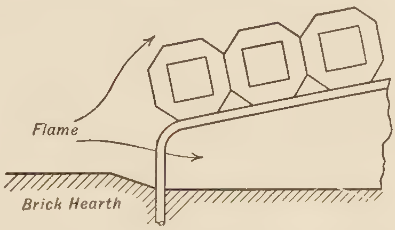

Fig. 204.—Soaking end of continuous furnace. Ingots drop from pipe skids on to soaking hearth.

The skid pipes of Fig. 205 break after a short time, on account of the impact caused by the falling of the heavy weights. The design represented by Fig. 206 was found to avoid the troubles incident to the pounding by blooms or ingots. At the foot of the skid pipes, a seamless tube with extra thick walls is imbedded in the magnesite hearth. It is water-cooled by a smaller pipe inside of it, and is firmly anchored in the sidewalls. The blooms turn over through 180 degrees, exposing the cold side to the heat.

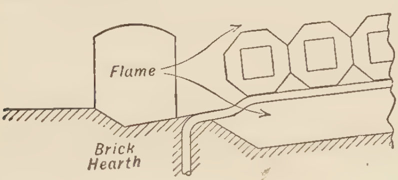

Fig. 205.—Soaking end of continuous furnace, with pipe skids arranged to roll ingot over when pushed on to soaking hearth.

If ingots are heated in a continuous furnace it is advisable to turn every other one end for end, so that the fins at the end of the ingots will not touch. If that arrangement is adopted, a turntable is usually provided at the discharge end of the furnace, for the purpose of turning every other ingot, and bringing the correct end to the mill.

In continuous furnaces that heat steel to rolling temperatures, scale is formed, particularly in the hot zone. If that scale comes in contact with very hot, pasty firebricks or with hot sand, it forms a slag.

If the hearth or the skid walls are built up of magnesite or chrome bricks, no slag is formed; and since iron oxide is practically infusible at the temperatures which prevail in industrial furnaces, the scale can easily be raked out or blown out, if the above-mentioned refractory materials are used, and if nothing but dry oxide drops down. If, on the other hand, molten metal is mixed with the oxide, the pieces of the latter are cemented together by the molten metal, and a pond of mill cinder is formed, which, upon cooling, freezes into a solid mass and requires hard labor for its removal. One may well ask why it should be necessary to melt some of the metal, when it is intended to heat the whole mass to a temperature below the melting point. The answer is that

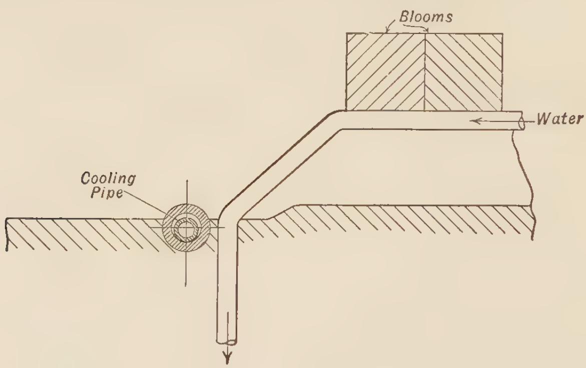

Fig. 206.—Method of turning blooms on fore-hearth.

certain ingots must be given a "wash-heat," that is to say, a heat close to the melting temperature, for the purpose of closing up blowholes under the hammer or the press, or in the mill. In raising the metal to that high temperature the furnace gases overheat and melt the projecting edges.

Scale, slag, and mill cinder must be removed from time to time, and the work of removing them is both hard and unpleasant. For that reason many designs have been made with a view to making this work easier and to save labor. The principle of most of them is to provide a place where the scale, slag, and cinders can collect, and to make that place easily accessible for drainage, raking out, and shoveling out. Figure 207 shows an arrangement in which the scale drops between the skid walls into a ditch; the latter reaches across the furnace to a side opening. If that

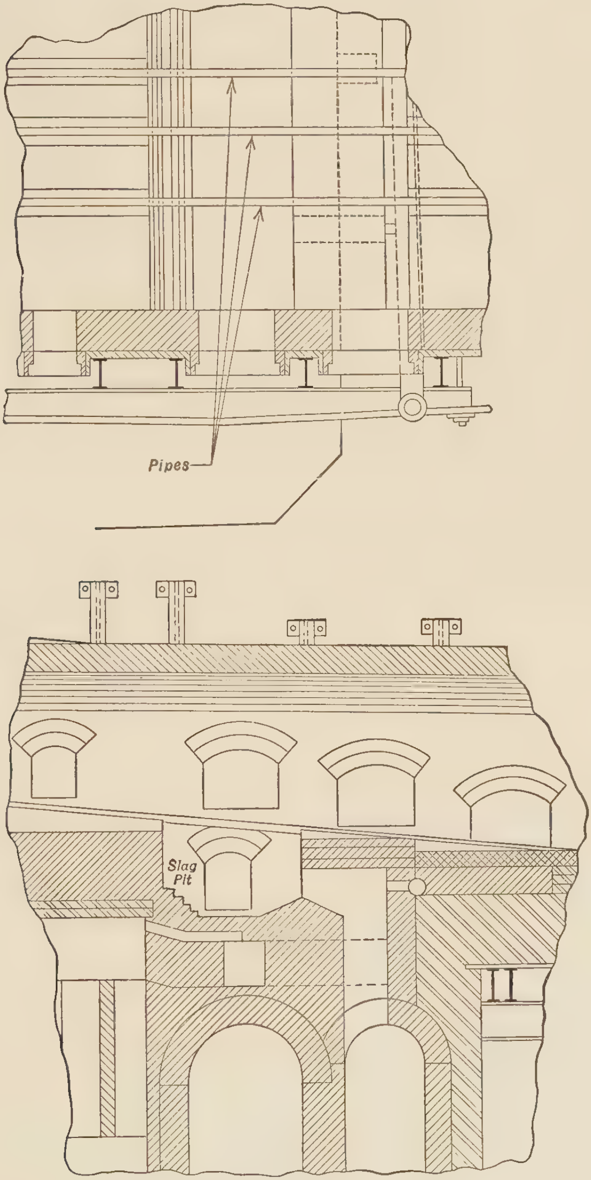

Fig. 207.—Section of continuous furnace, showing cinder channel.

opening is to be useful, room must be provided on the outside of the furnace for reaching in with a long-handled hoe or shovel. If slag is to be formed and is to run off, a sand bottom is provided in the ditch, and heat is applied to keep the temperature above 2000° F. On the outside, the tapping hole is surrounded by a basket filled with burning coal, for the purpose of keeping the hole open. The slag runs into receptacles which have wheels and are equipped with long handles for ease of manipulation.

In this connection the fact may be mentioned that, at least in continuous furnaces, ease of cinder removal and fuel economy do not go together. Continuous furnaces have been constructed in which the $2\frac{1}{2}$-inch diameter skid pipes rest on 4-inch diameter cross pipes. In this manner there is provided, under the skid pipes, an unobstructed space, in which cinder can collect, and from which it can be removed easily. The heating capacity and the fuel economy of such a furnace are much below the corresponding quantities of those furnaces in which the skid pipes rest on walls.

One of the most important pieces of labor-saving equipment in connection with continuous furnaces is the pusher which moves the stock through the furnace. Pushers are either of the fluid-displacement type, or of the electric-motor type. In the displacement type a fluid, such as compressed air, steam, oil, or water under pressure, acts upon a piston and moves it forward. The motion is then transmitted to the stock, directly or by means of a lever mechanism. In the electric-motor type the motor operates a screw, a rack, or a crank, through suitable gearing, and the motion is again transmitted to the stock by means of mechanisms. No matter what type is used the following remarks are of importance. The pusher does not work continuously but only intermittently. In consequence, the material to be moved starts from rest with every forward stroke of the pusher, which means that the friction of rest must be overcome. After motion has begun, friction is, of course, reduced to a somewhat lower value. Tests indicate that the friction coefficient between hot steel and cold steel is approximately 39 per cent at the start and drops to about 34 per cent if motion is maintained. This coefficient is so great in comparison to the weight of the steel that it makes very little difference, as far as power requirements of the pusher are concerned, whether the steel is pushed horizontally, slightly down-

ward, or slightly upward. The inclination of the skids is, as a rule, determined by other considerations than by that of power requirements of the pusher.

Whenever material of a uniform size is pushed through the furnace the pusher can work with a constant stroke. If, on the other hand, material of varying sizes is pushed through the furnace the stroke of the pusher must be adjusted to suit the material, so that pieces can be pushed off the skids positively, one by one. In an hydraulic pusher such as that shown in Fig. 208 it is very easy to adjust the stroke of the pusher, because

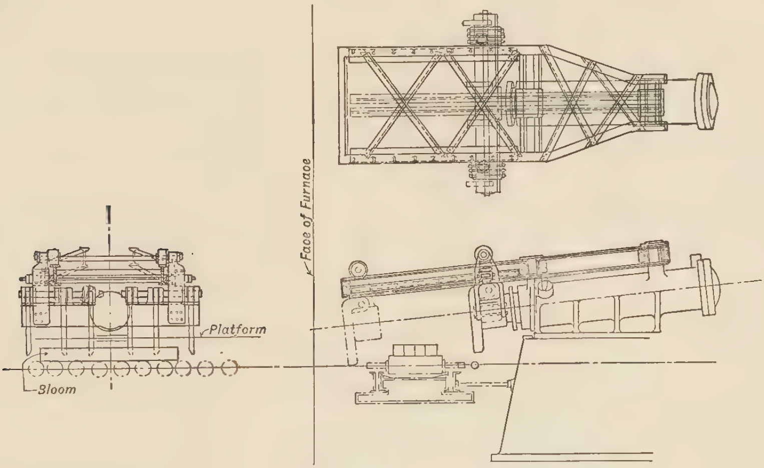

Fig. 208.—Hydraulic pusher for continuous furnace.

turning off the valve which regulates the water supply immediately stops any further motion of the pusher. With steam or compressed air as the moving agent, motion is still reasonably certain, in spite of the expansive force of the elastic fluid, because the power can be turned off just before the desired point in the stroke has been reached, and because the force is so quickly reduced by the expansion on one side of the piston and by the compression on the other side that no further motion occurs. Besides, the power can be reversed if necessary, or the driving fluid can be exhausted from behind the piston, by which action the pusher is likewise stopped. Electrically operated pushers can also be stopped anywhere, because motors can be equipped with

quick-acting magnetic brakes. In crank-operated electric pushers, an example of which is shown in Fig. 209, the arrangement is frequently such that the crank makes a full revolution for each piece going through the furnace. In that case adjustment of the stroke requires adjustment of the length of the crank or of the lever arm transmitting the motion from the crank to the stock. It is, of course, possible to use a reversing motor in this case also, and to let the crank make less than a half revolution, bringing it back to the original position by reversing the motor.

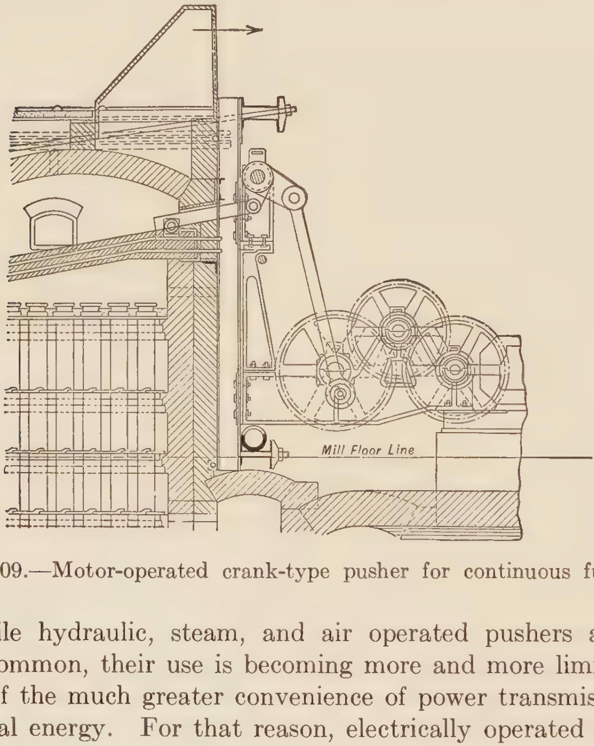

FIG. 209.—Motor-operated crank-type pusher for continuous furnace.

While hydraulic, steam, and air operated pushers are still quite common, their use is becoming more and more limited because of the much greater convenience of power transmission by electrical energy. For that reason, electrically operated pushers are found in most new installations, in spite of their somewhat greater cost. A screw-operated electric pusher is illustrated in Fig. 210, while Fig. 211 shows a design in which an electric motor drives a rack through suitable reduction gearing and through a pinion. In this design the straight-line motion of the rack takes the place of the straight-line motion of the piston rod in the hydraulic pusher. It will be noted that the pusher head disappears below

the rails when drawn back. While it is in that position, the bars to be charged are brought to position above and in front of it, by the transfer chain. The motor operating the pinion is started, and as the pusher head moves forward it also rises above the level of the rails, and pushes the bars into the furnace. Electric pushers containing a rack or a lead screw must be provided with limit switches to prevent overrunning.

A late development in pushers for a number of furnaces con-

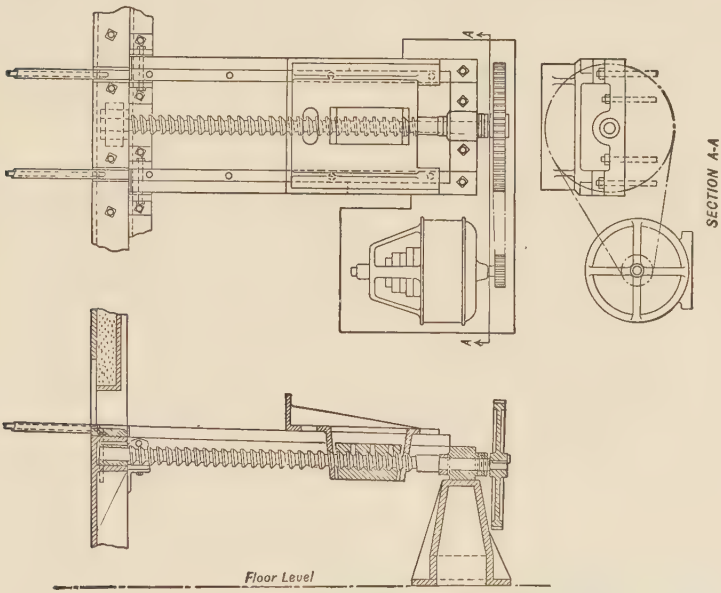

FIG. 210.—Motor-operated pusher of the screw and nut type.

sists in using oil pressure in hydraulic pushers and in providing a storage tank in which the pressure of the oil is maintained by air pressure. A small electric motor operates a small oil pump, which delivers the oil to the tank. The advantage of this system consists in the simplicity and ruggedness of the hydraulic pusher and in the comparatively low cost of a single small motor. The oil used is light enough to stay fluid in cold weather.

The pusher has to exert the whole frictional force for moving the stock through the furnace. This force is of considerable magnitude in connection with large furnaces, and the pusher

must be well anchored. If the stock is pushed over skid pipes it is customary to fasten the skid pipes rigidly to the pusher and to let them expand freely at the hot end of the furnace. By this method of design the forces become self-contained between the pusher, the stock, and the skid pipes.

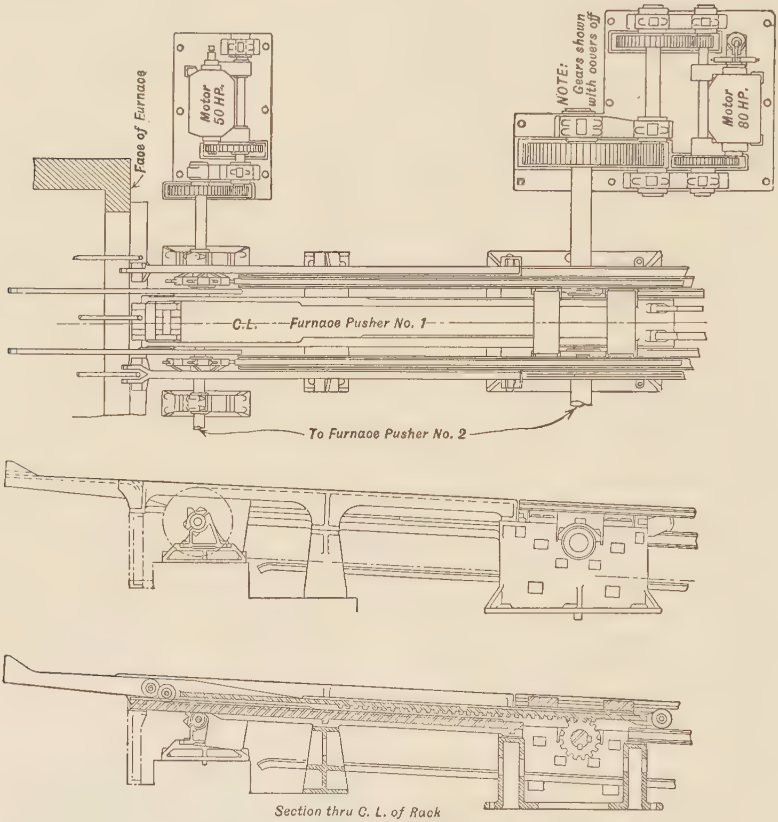

FIG. 211.—Furnace pusher of the rack and pinion type. This pusher is combined with a transfer for steel bars.

Pushers frequently take up a great deal of space at the charging end of furnaces. For that reason they are occasionally put underneath the charging platform and reach up to the latter by means of levers (compare also Fig. 202). When this arrangement is used the forces transmitted through the lever and through the

support of the fulcrum must be considered in relation to the strength of the structure.

For convenience of comparison several arrangements of pushers are assembled in Fig. 212. They are shown to be operated by hydraulic cylinders, but the same arrangements can be used with electric motors.

In wide furnaces for the heating of long billets problems are presented in connection with the entry and with the discharge of the billets. These problems were solved by the use of water-cooled rollers for entrance, and a power-operated push-out rod for discharge. The water-cooled rollers, which project a small

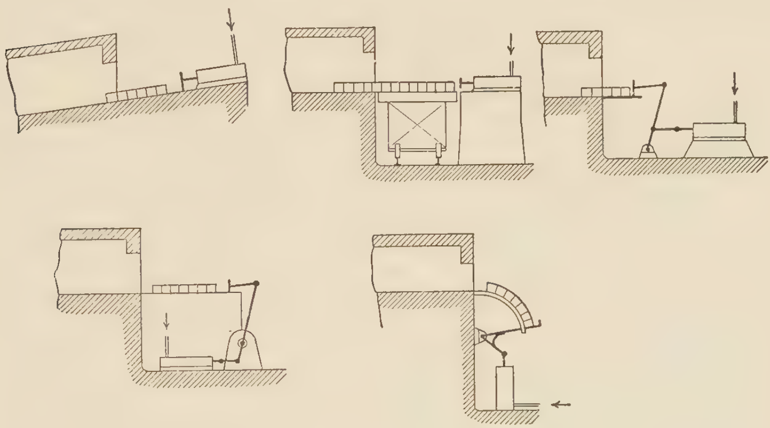

Fig. 212.—Diagrammatic sketch of five arrangements of furnace pushers.

distance above the skid pipes, are shown in Fig. 213. In this illustration the drive of the rollers is clearly seen. The inclination of the rollers holds the billets against the rear of the furnace. The billets bump against a spring-cushioned stop.

The power-operated push-out rod is illustrated in Fig. 214. The furnace man places the push-out rod behind the billet which is to be pushed into the mill. He then steps on a pedal and, by this action, operates the valve which admits water pressure to an hydraulic cylinder. The latter pushes a pinch roller up against the push-rod, which is forced up against a continuously rotating power-driven roller and is forced into the furnace by the friction between the push rod and the roller. The work of pushing the billets out of the furnace is made quite easy by this machine,

except at times when billets stick together. However, sticking should not occur, and is usually the heater's fault

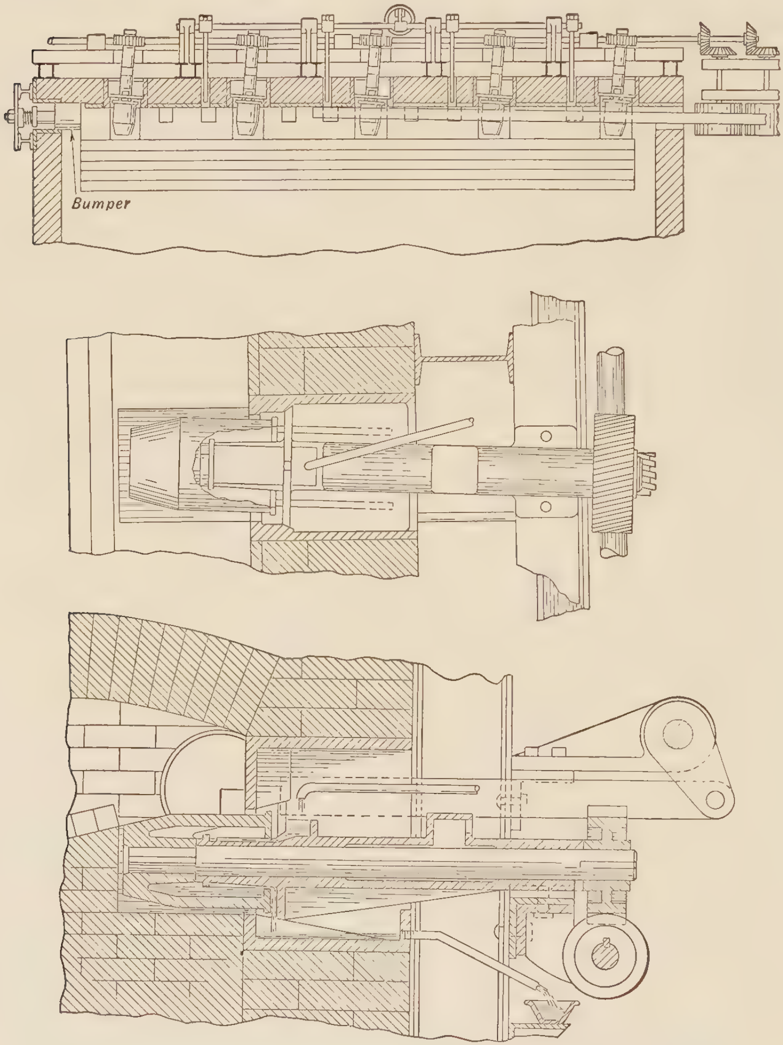

Fig. 213.—Power-driven rollers for carrying long billets into furnace.

A large amount of material is pushed through furnaces indirectly, that is to say, on trays or containers. This method of moving material through a furnace involves an unpleasant task,

namely, that of returning the containers from the hot, or discharge, end to the cold, or charging, end. All sorts of conveyors have been used for returning the containers, either over the top of the

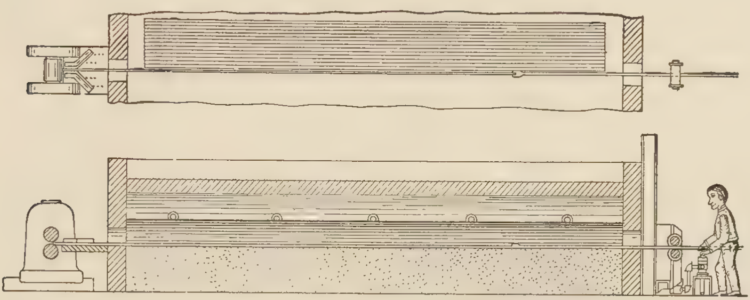

FIG. 214.—Power-operated push-out rod.

furnace or underneath. Monorails are also used for taking the trays back along the side, but one of the simplest schemes is that of providing an inclined plane along one side of the furnace,

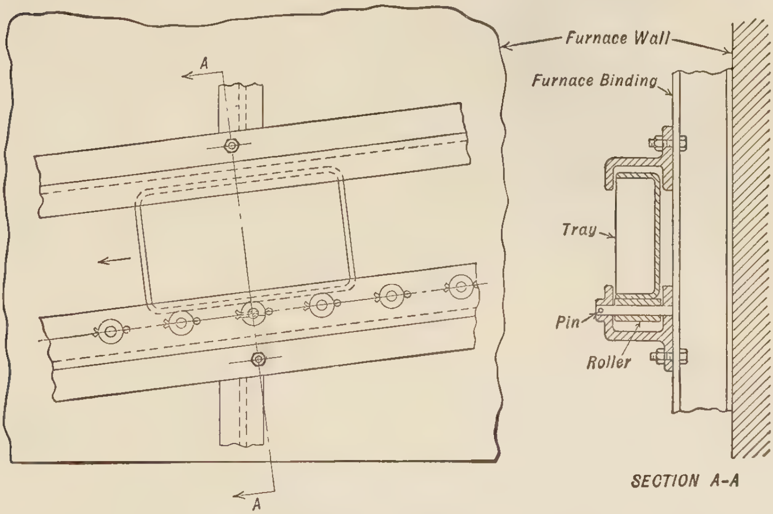

FIG. 215.—Method of returning containers to charging end of furnace.

placing the tray on rollers and allowing it to go back on these rollers to the charging end. Figure 215 indicates diagrammatically how this has been done for flat trays. The latter are placed

on end, that is to say, they are turned in such a way that they stand up and occupy very little space laterally. They run on rollers, which are shown in the illustration, and are guided in such a way that they cannot fall over. This device has been very effective and very economical of labor. In shops with ample space the trays are returned on wide rollers, such as are used for the conveying of bricks. An arrangement of this kind is illustrated in Fig. 216.

FIG. 216.—Continuous furnace with return for containers.

Roll-over Furnace.—This furnace is the original continuous type. It is anything but labor-saving, because men must reach through side doors, and must, by means of tongs or crow bars, turn the ingots or blooms over, thus rolling them from the cold end to the hot end. In spite of the advantages of very uniform heating which this type offers, it has disappeared for general purposes, on account of the disagreeable labor which it involves. It still survives in tire furnaces, through which round slices of ingots, or forged discs, are rolled by hand. This design is so limited in its application that no illustration is given here.

Rounds for other purposes are frequently rolled through continuous furnaces by the action of gravity. An example of that method is offered in Fig. 217, which represents a furnace for heat-treating gear blanks, shells, or other material of round shape. The inclination of the hearth is of much greater importance in continuous furnaces through which rounds are to be rolled than in those through which material is to be pushed. One of the determining features is the temperature to which the rounds are heated. Very hot rounds are pasty, and rest on the hearth with

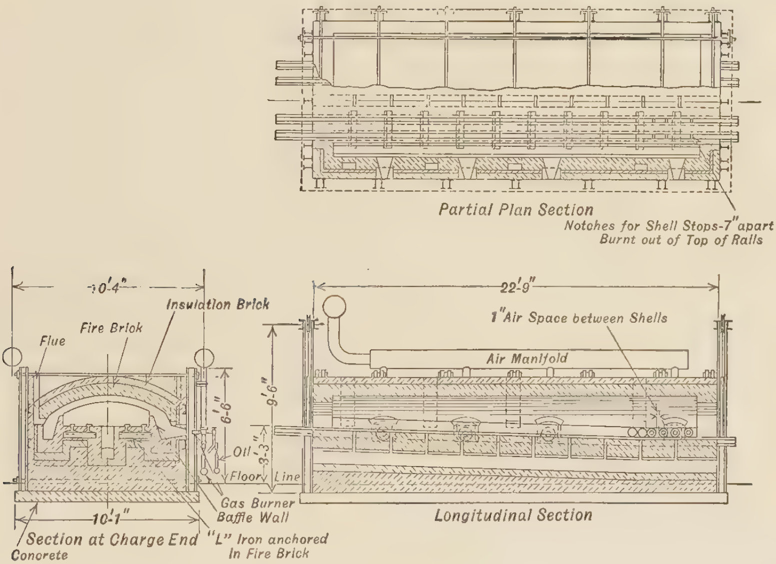

Fig. 217.—Continuous furnace for heating round shapes to 1600° F.

a flat spot. For that reason the hearth must have a greater inclination for very hot rounds than is correct for a lower temperature. This slope is usually made about one inch in 12 inches length in furnaces having a temperature of 2200° F. It is notoriously difficult to fill a cold furnace built for very hot rounds. The inclination should be such that if one of the round pieces is withdrawn at the discharge end, the rest of the material moves a short distance through the furnace without emptying all the stock on to the floor. For that reason a horizontal section is arranged at the bottom of the incline, or else a stop mechanism is

provided for preventing any undesirable motion of the rest of the charge in the furnace. Such a stop motion is indicated in Fig. 132, which represents a continuous, electrically heated furnace for annealing piston rings. It will be seen that a "square with curved sides" serves for holding the last set of piston rings, and for moving

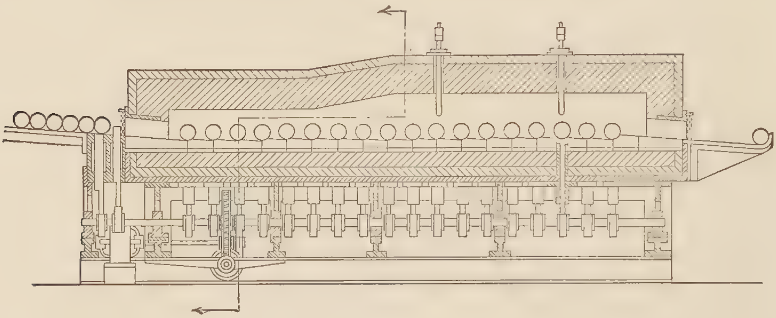

Fig. 218.—Automatic furnace for heating rounds. Longitudinal section.

it out of the furnace, at the same time catching the next set and thereby stopping further motion of the rest of the charge. When the bottom round is withdrawn the rest of them start opening up at the bottom, the motion gradually progressing from the bottom to the top. This means that they do not start rolling all at once; the bottom ones roll first and those at the top roll last.

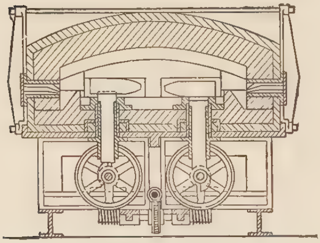

Fig. 219.— Automatic furnace for heating rounds. Cross-section along dot-and-dash line of Fig. 218.

A special furnace for rolling rounds along a hearth is shown in Figs. 218 and 219. This furnace was designed for the purpose of heat-treating shells for guns at a time when the demand for that material was very brisk. Underneath the hearth of the furnace lies a shaft (or two shafts in wide furnaces) carrying a number of cams. These cams lift up tappets with inclined faces, which in turn lift the shells successively off their seats and roll them forward in the direction in which the steel is to move through the furnace. The cams are so arranged that motion of the rounds begins at the discharge end and that each shell, when it moves into the next compartment, finds room into which to move.

This furnace was quite successful for its purpose. It was a single-purpose furnace, the installation of which was predicated upon a demand for vast quantities of a given size and shape of heated material. It may be remarked at this point that furnaces having movable plugs in the hearth and "fins and gills" underneath are suitable only for those temperatures at which no serious scaling takes place, because it is evident that scale or slag would soon

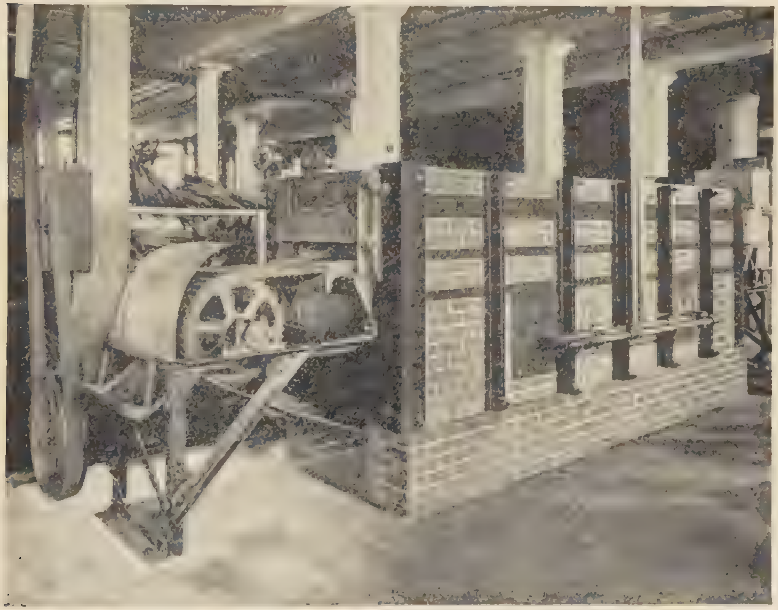

FIG. 220.—Automatic furnace of the chain-conveyor type.

render the operating mechanism ineffective by clogging it or corroding it.

Conveyor Furnaces: Chain Conveyors.—Among the various types of conveyors for automatic furnaces, the chain is very popular. The appearance of a furnace with a chain conveyor is shown in Fig. 220. The comments of furnace users on chain conveyors are most varied, and extend over the whole range of opinion, from "Excellent, no trouble at all" to "Extremely unsatisfactory, nothing but trouble." The temperature to which the chain is heated is the determining factor. Very little trouble arises at temperatures below 1200° F. At 1400° F. some care

must be taken in design, selection of material, and in operation. At 1600° F. chains cause a great deal of trouble, unless they are specially designed and well taken care of. For still higher temperatures they cannot be recommended.

The shape of the conveyor chains for furnaces varies widely with the shape of the material which is to be transported. It also depends upon the location of the chain, as explained below. If the chain is to carry pieces of varying size and shape, two designs are possible. There may be one multiple chain, consisting of many links side by side so as to offer a virtually unbroken and almost flat surface in the furnace; or there may be two or three separate chains, with framework between the links or carried by them and projecting above them. In furnaces with a comparatively low temperature, say, not exceeding 1200° F., the multiple chain is very convenient, because it is standard and needs no attachments. Ordinary block or roller chains are very common for this purpose. Commercial link chains, such as those made by any of the manufacturers of elevating, conveying, and power transmission machinery, are frequently installed in those furnaces in which the chain does not pass through the heating chamber but passes either underneath the hearth proper or else outside of the furnace, and in which only the attachments to the chain reach into the furnace. Such a furnace is shown in Fig. 221. In cases such as the one shown in the latter illustration, pieces of almost any conceivable shape can be carried through the furnace, because special pieces for carrying the material to be heated can easily be attached to standard links. The makers of link chains furnish links with flat surfaces and bolt holes for attaching anything that may be desired.

For chains which stay at or near room temperature practically all the time the ordinary method of taking up the slack by means of screw adjustment is very satisfactory. On the other hand, it causes trouble with chains which are subjected to varying temperatures. If the take-up is adjusted to make the chain reasonably tight when it is hot, the chain will be stretched beyond its elastic limit or may even break when it gets cold. The slack of chains with variable temperature must be taken up by a spring or a weight. The take-up is always arranged at the end which is not driven. As a rule, only the sprockets at the discharge end of the furnace are driven, while the other set of sprockets are idlers.

It is, however, not absolutely necessary to pull the chain through the furnace; it can be pushed through, if made of the proper shape. Figure 222 presents a view of a push chain, consisting of a series of flat trays which are hinged at the ends. The moving force of the chain is not transmitted through the joints while the chain

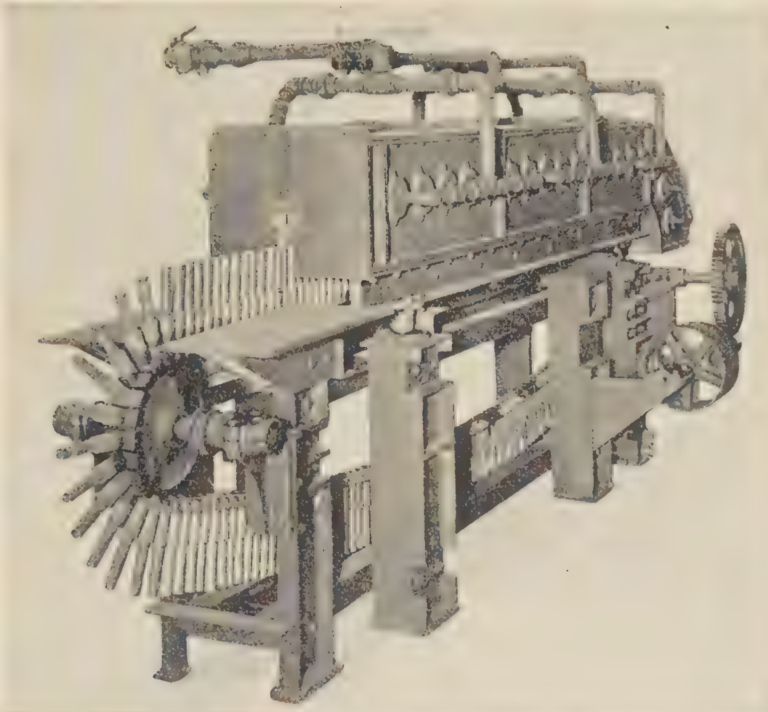

FIG. 221.—Automatic furnace with chain outside of furnace.
Note tubular attachments for carrying engine valves through furnace.

is in the furnace, but by direct contact between the broad sides of the individual links or trays.

When chains are used at temperatures above 1200° F. their expansion becomes quite troublesome. The sprockets over which the chains turn retain a temperature very close to that of the room, whereas the chain is hot. In consequence, the links of the chain become too long for the pitch of the sprockets and have a tendency to climb up. On account of friction between

link and sprocket tooth, the link does not slip down into its proper place as the sprocket revolves, but continues to ride higher up on the side of the tooth; the next link, the pitch of which is also longer than the pitch of the sprocket teeth, when coming into contact, rides still higher up; until finally one link catches on top of a tooth, and breaks the chain. This does not happen in every case, but chiefly where the sprocket teeth are poorly designed, with insufficient clearance.

Fig. 222.—Conveyor chain with tray-shape links. The links are pushed through the furnace.

If there are temperature differences across the furnace, some strands of the chain become hotter than others; and, since all chains pass over the same driving sprocket, one strand of the chain will pull against another, thus causing some of the links to stretch, with a tendency to buckle another set. In consequence of these various troubles many furnace builders fight shy of chains except for temperatures below 1400° F. It is certain that no inexperienced designer should use chains in furnaces, except for low tem-

peratures. If chains are to be used for temperatures of 1400 to 1600° F., the responsibility should be left to those furnace builders who have learned to overcome, or at least mitigate, the many troubles which arise in the use of chains in furnaces carrying temperatures above 1200°.

A design intended to protect the conveyor chain from the effects of a hot furnace, and thereby to avoid chain troubles, is shown in Fig. 223. It will be seen that the chain travels in a water-cooled guide below the hearth and that prongs or cross bars of heat-resisting material extend upward from the chains and act as carriers for the stock or charge. It is quite evident that any

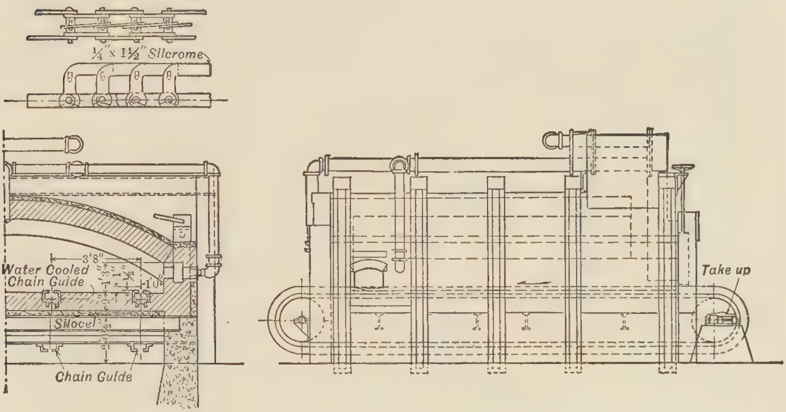

FIG. 223.—Automatic furnace with chain in water-cooled guide.

scale dropping down into the chain guides is apt to cause wear, or even sticking. Nevertheless, this design is, for many purposes, superior to the one in which the chain is exposed to the heat. It cannot be used if very small pieces are to be carried. A chain design which stands half way between Fig. 221 and Fig. 223 is exhibited in Fig. 224. It represents the discharge end of a 1200° F. furnace for "drawing" automobile front axles after quenching. Fins of heat-resisting material are attached to a roller chain which travels in a groove immediately under (and partly in) the hearth. If heat is to reach the under side of the pieces which are transported through the heating chamber, the vertical arms of Figs. 223 and 224 must be long. In that case any unevenness of the surface in the guide boxes for the chain causes a perceptible

rocking motion of the vertical carrier-arms, and a relative motion between the top of these arms and the stock being carried. While this relative motion is harmless in most cases, it scratches sheets at temperatures above 1300° F.

Heavy conveyor chains of malleable iron or steel can be used for carrying light objects through a furnace of comparatively high temperature if fuel economy is no object. If a heavy chain, with projections on which light stock or thin discs are carried, travels through a hot furnace, these light pieces will be heated through

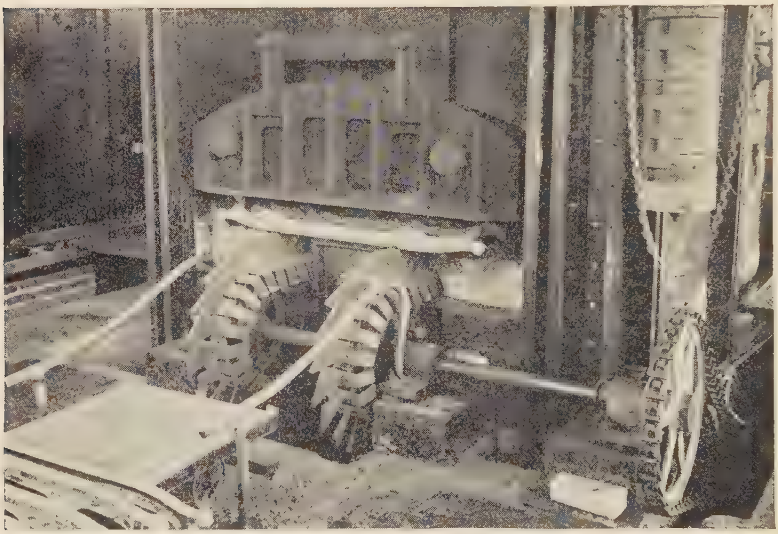

FIG. 224.—Discharge end of chain-conveyor furnace for automobile axles. Note carrying fins attached to chain and bent pipes for conveying axles to truck.

before the chain has become perceptibly warm. In other words, the thin pieces will be red hot all the way through when the chain is still black. The chain is protected against gradual rise in temperature due to repeated passages through the furnace, by running through water on its return travel under the furnace. This method of moving material through a furnace exhibits very plainly the conflict between labor economy and fuel economy.

At temperatures in excess of 1000° F., chains of malleable iron and of steel are oxidized, the rate of oxidation depending upon the temperature. Chains made of heat-resisting materials, such

as chrome or nickel alloys of iron, can be used at higher temperatures without noticeable oxidation, but they do not necessarily do away with the above-mentioned troubles of expansion and of stretching of the chain links and of their wedging. The nickel alloys, in particular, suffer from segregation and are subject to considerable warping, unless extreme care is used in making them. Alloys of iron and chromium are reported to warp very little; rolled material warps less than cast material.

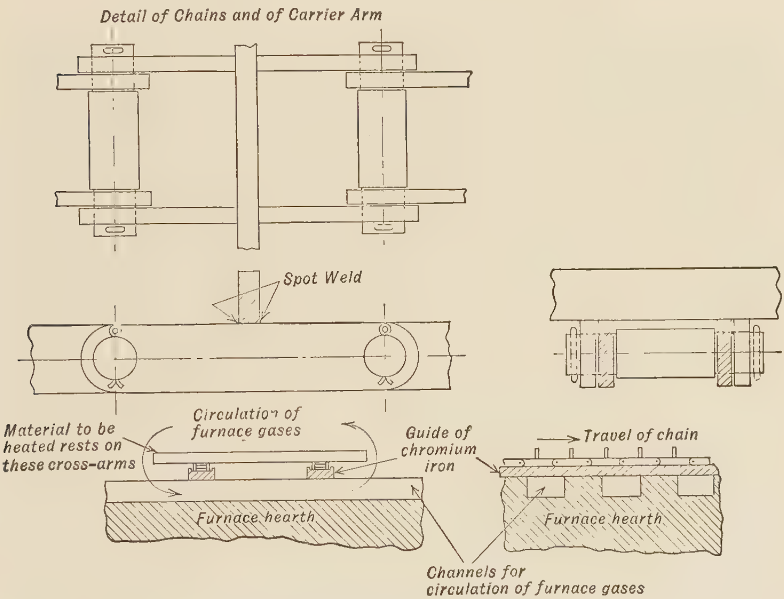

FIG. 225.—Alloy chain for traveling through hot furnace.

Note that carrier arms are welded to both strands of the chain.

In heat-treating and normalizing work, that is to say, in furnaces working with temperatures between 1400° and 1700° F., heat economy cannot be obtained unless the chain retains the heat which it has absorbed in the furnace. Retaining the heat is especially desirable if electrical energy is used for heating, on account of the high cost of that energy. In that case the chain is exposed to furnace temperature both on the transporting travel and on the return travel.

Figure 225 represents a design of chain and of support which has been used successfully in several cases. A forged or rolled,

well-annealed, high-chromium alloy of iron serves as material for the chain. It may be remarked once more that success with chain conveyors depends not only upon the properties of the chain, but also upon uniform distribution of temperature in the furnace. The best chain design is of no avail if parallel strands of the chain are subjected to great differences of temperature.

In chain-conveyor furnaces, except in very short ones, the chain cannot be kept taut enough to be free from the furnace hearth. In the majority of cases it drags on the hearth. The latter must then be very smooth and is preferably provided with iron, steel, or alloy rails upon which the chain can slide or roll. Occasionally, water-cooled or alloy rollers, reaching across the furnace, are provided for carrying the chain. Chains have also been equipped with refractory tops and, when so equipped, have transported material through very hot furnaces. A chain element for this purpose is illustrated in Fig. 226. The illustration shows a cross-section through an element on its return under the furnace. The method of supporting the weight of the heavy refractory block is clearly visible. Chains consisting of refractory blocks can be used up to the highest temperatures. Troubles arise from spalling of the refractory material, due to frequent and extreme temperature changes, and from the loss of heat on the return travel.

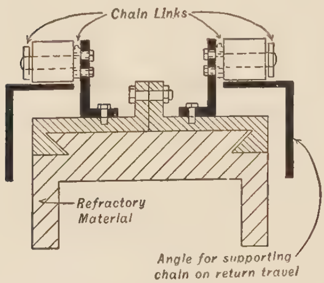

FIG. 226.—Roller chain with carrier arm of refractory material. Chain is shown in the position which it assumes on the return travel under the furnace.

Chain conveyors can be so arranged that the stock is discharged automatically from the chain into quenching tanks, cars, or buckets, at the place where the chain turns, or even on automatic conveyors which take the heated or heat-treated material automatically to the place where the next step in manufacturing is performed.

Material to be heated can be delivered to a furnace by an external chain conveyor which automatically deposits the stock on the furnace chain. Two arrangements of this kind are illustrated in Fig. 227. In the foreground a link chain conveys axles from the quenching tank and deposits them on curved guides

bent from pipes. The axles slide from the pipe guides to the chain, which was illustrated in Fig. 224. In the background of Fig. 227 another external conveyor is visible. It is built up of angles which are riveted to the links of a roller chain. This conveyor likewise picks material out of the quenching tank and deposits it on a furnace chain.

Conveyors such as shown in Fig. 227 are a profitable investment if large quantities of identical pieces are to be heated.

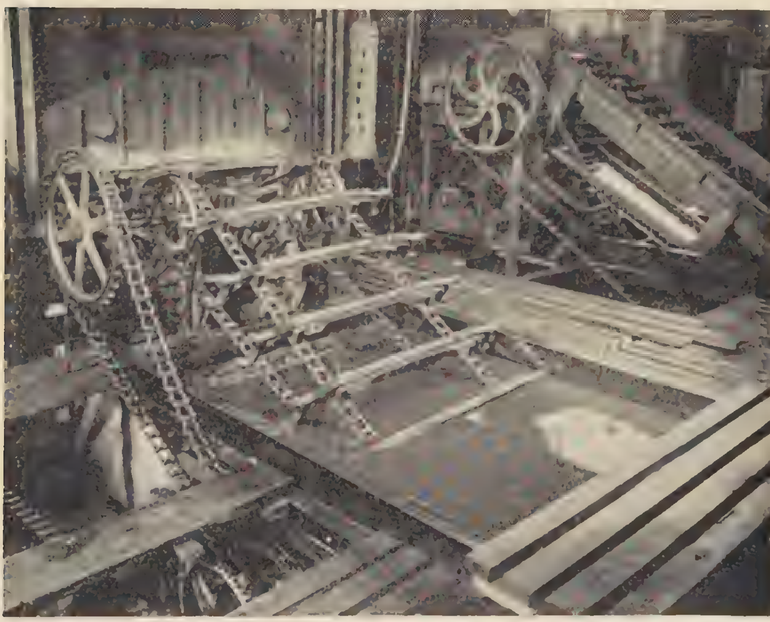

Fig. 227.—Auxiliary conveyors for delivering material to furnace conveyors.

Compared to the pusher, the chain conveyor has the advantage that material of almost any shape can be placed upon it and can be conveyed through the furnace.

Belt Conveyors.—The use of belt conveyors in industrial furnaces has not been tried to any extent. The reason is evident. Belt conveyors, to stand up in a furnace, must be of heat-resisting metal, and must be extremely thin in order to be so pliable that they will fold around a drum of reasonably small diameter. Thin metal ribbons rust out or otherwise corrode very quickly. For

this reason, belt conveyors cannot be seriously considered until heat-resisting metals can be rolled into sheets and welded into an endless belt. With the advent of iron-chromium alloys, consisting of about 70 per cent iron and about 30 per cent chromium, the use of belt conveyors in industrial furnaces comes within the range of possibility. Doubtless, trials and tribulations will occur, be-

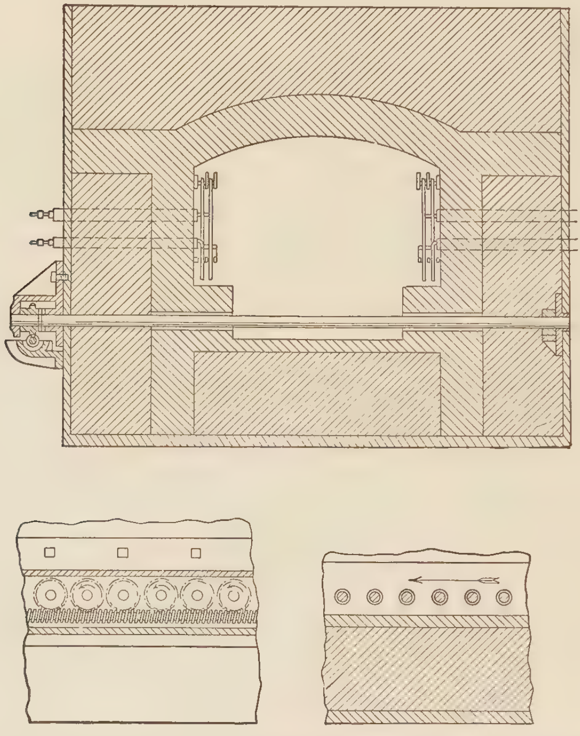

FIG. 228.—Roller conveyor in electrically heated furnace. The rollers are made of heat-resisting metal.

cause uneven temperature in the furnace will have a tendency to cause a waviness in the belt or even tearing at one of the edges. It would not be surprising, however, if belt conveyors for industrial furnaces had become a reality by the time this book was published.

Roller Conveyors.—As a rule chains leave the furnace and are returned to the starting point outside of the furnace. They take heat out of the furnace and dissipate it. The repeated expansion

and contraction to which chains are in this manner subjected is injurious to most materials. The roller conveyor overcomes several of these difficulties. In its simplest design, it consists of a number of revolving rods which are driven from a shaft outside of the furnace. Figure 228 illustrates such a design. In this particular application the rollers are made of a heat-resisting alloy, which can assume furnace temperature without being damaged. The method of driving the rollers from outside of the furnace, by means of worm gears and a long screw, is clearly shown in the illustration. The rollers must revolve fast enough to prevent any noticeable temperature difference between top and bottom; otherwise warping is inevitable.

Before the advent of heat-resisting metals the construction of rollers for furnaces offered many difficulties. One of the early designs is shown in Fig. 229. In this roller, annular shapes of refractory material were clamped between collars and springs on a water-cooled tubular shaft. The roller shown in Fig. 229 was intended to move heavy sheets and light plates through a furnace. It was given its concave shape for the purpose of keeping the sheets in the center of the roller. The great curvature, however, defeated the very object which it sought to attain. The sheets traveled through the furnace in zigzag fashion, climbing up on the rollers and then sliding down, only to climb up on the other side. For that reason the rollers were later made almost cylindrical. The refractory rollers did not do well at the very place where they were expected to be most desirable, namely, at the firing end of the furnace; and they were replaced by steel discs fastened to a water-cooled shaft which lay in a slot. A stoker-fired furnace with the two types of rollers is illustrated in Fig. 230. As far as temperature effects are concerned, the discs worked quite well, because any given point on the periphery of the steel disc is below the hearth a large part of the time, and is exposed to the furnace heat only a comparatively short time. Besides, the discs are covered by cold plates a large portion of the time. In a later design, piers or walls were provided between the rollers,

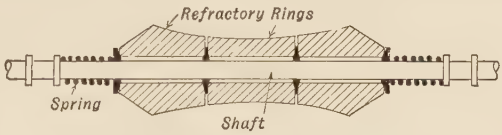

FIG. 229.—Composite roller for transporting plates through a furnace.

and the depressions in which the shafts lie were covered with tiles.

While these designs proved to be satisfactory for gas- or oil-heated furnaces, they caused great trouble at the hot end of furnaces fired with powdered coal. The ashes filled the spaces between discs and hearth, causing the discs to bind, to wear away, to stick, and finally to break the driving mechanism. This experience emphasizes the fact that conveying equipment which is very successful with one set of furnace conditions may be an

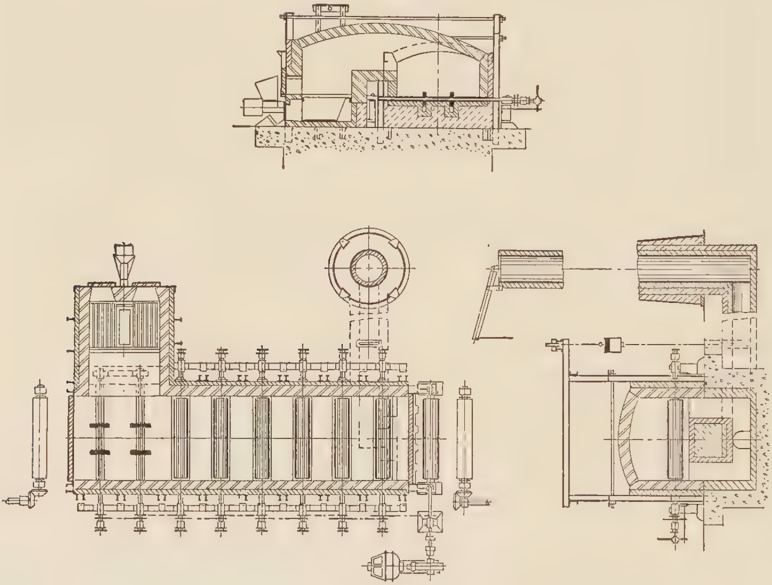

Fig. 230.—Plate-annealing furnace with roller conveyor.

utter failure with different furnace conditions. In this respect, furnace temperature and furnace atmosphere are of importance. Steel discs, which last a long time in a furnace temperature of 1400° F. and in a reducing atmosphere, must be replaced much more often if they work in a temperature of 1600° F. or in an oxidizing atmosphere. If discs are to be used under the latter conditions, they must be kept cool, if made of steel, or else they must be made of a heat-resisting alloy. In the latter case, the discs and the shafts on which they ride can be located entirely above the hearth. As a rule, the discs are staggered on successive

shafts, with the result that even small and thin plates or discs can be moved through the furnace on rollers. Such an arrangement is shown diagrammatically in Fig. 231.

With few exceptions, the cross shafts are water-cooled, and some difficulty then arises on account of the expansion of the discs due to the furnace temperature. They are intended to remain in contact with the water-cooled shaft at the center, where they stay cold; at the same time the hot periphery tends to expand. This action has caused discs to crack near the center, while others have come loose from their shafts. Designs will doubtless be developed to overcome this trouble, because the roller-type furnace is a very great convenience for heating sheets, thin plates, and similar materials. The water cooling of the shafts causes considerable heat losses. Calculations, which can be made rapidly with the help of Fig. 61, page 76, of Volume I, show that, in many cases, the heat absorbed by the shafts by far exceeds the heat imparted to the plates or sheets. It also results in non-uniform annealing or normalizing, because the bottom of the furnace stays cold. The above-mentioned design, in which the shafts turn in covered grooves, is free from these two disadvantages. If closely spaced shafts with staggered rollers are to be located entirely above the furnace hearth, it will pay to surround the shafts with insulation which is packed in tubes of heat-resisting metal.

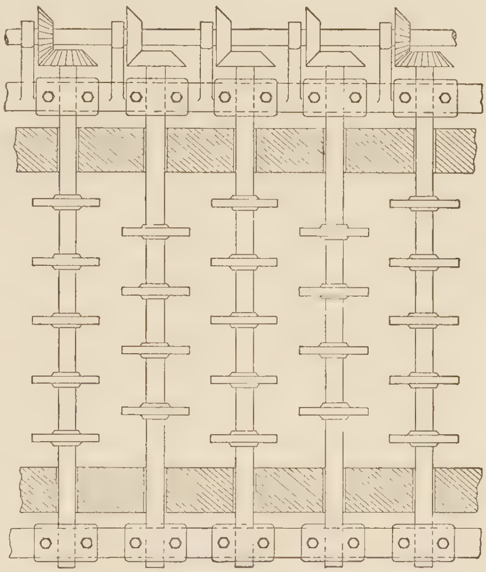

FIG. 231.—Roller conveyor for sheets and plates.

The roller-type conveyor cannot be used if pieces with projecting parts are to be moved through the furnace, because

the projections would drop between the rollers and would stick.

An inspection of Fig. 230 shows that the cold sheets enter at the hot end of the furnace. The purpose of this arrangement was to avoid overheating of the sheets or of the rollers, without having to resort to perforated bridgewalls or arches. In modern continuous furnaces for annealing or normalizing sheets the latter enter at the cold end. Compare Fig. 110. In the furnace in question it was intended to remove the sheets or plates quickly at the discharge end. For this purpose the last rollers were run at a high speed in some cases; and in others, pinch rollers just outside of the furnace removed the plates at high speed. These arrangements were found to scratch the plates or sheets. In consequence, modern furnaces are built so long that the material travels through them at a fairly high but constant speed from beginning to end.

The driving of the rollers is invariably done on the outside of the furnace. An example of such a drive, in which worm gears are used, was given in Fig. 228. Another method consists in putting bevel gears on the shafts of the rollers and driving them by means of bevel gears on a lay shaft, which extends along the whole furnace. Still another method consists in putting sprockets on the roller shafts and driving these sprockets by means of an endless chain. The chain drive is comparatively inexpensive; but the rotation of the rollers is jerky, and the sheets (if such are being heated) are scratched rather severely. Water cooling of the shafts and bearings is usually necessary. Provision must be made for replacing damaged rollers and shafts without tearing the furnace down.

Rollers can also be used for moving cylindrical shapes through furnaces, as illustrated in Fig. 232, which shows a method of conveying pipes through an annealing furnace. It will be noted that about three-quarters of the circumference of each roller is circular, and the other quarter has a cam-shaped depression. As the rollers turn continuously, each pipe is first rotated without forward motion; then it rolls into the depressions or grooves in the rollers and is lifted over into the next notch formed by the intersection of the roller circumferences. There it is again rotated until the next cam-depression comes around and moves it forward another step. In the illustration, the rollers rotate clock-

wise, and the pipes travel from left to right. In the upper part of the illustration the pipes are shown in position just after they have dropped into the depressions; in the lower part of the figure they are shown in an intermediate position, where, after

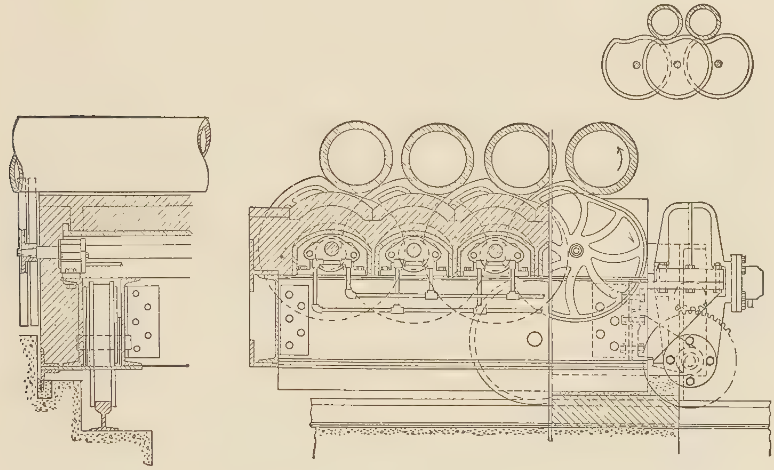

FIG. 232.—Roller conveyor for transporting pipes through annealing furnace.

dropping into the depressions, they have been moved part-way forward but have not yet been raised to the normal level. The continual rotation of the pipes has the advantages of permitting uniform heating and preventing sagging.

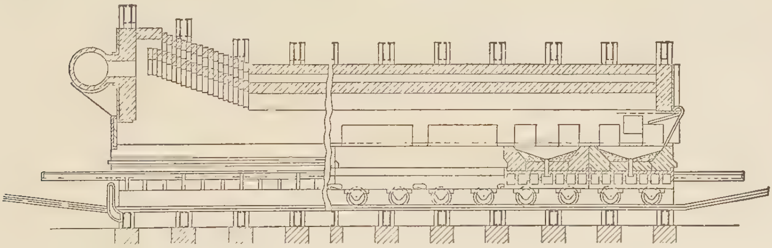

FIG. 233.—Continuous furnace with car-type conveyor.

Car-type Conveyors.—The car-bottom furnace has so many advantages with regard to ease of loading and unloading of heavy charges that its use has suggested itself to many engineers for continuous conveying of materials through furnaces. The general

principle of the continuous car-type furnace is illustrated in Fig. 233. The car-bottom conveyor has been developed to a high state of perfection in the continuous annealing furnace of the tunnel kiln type. A car from such a furnace is shown in Fig. 234. The photograph shows several interesting features. The car must be strong enough to transmit the push which is required to move the whole string of cars. At the ends where the car

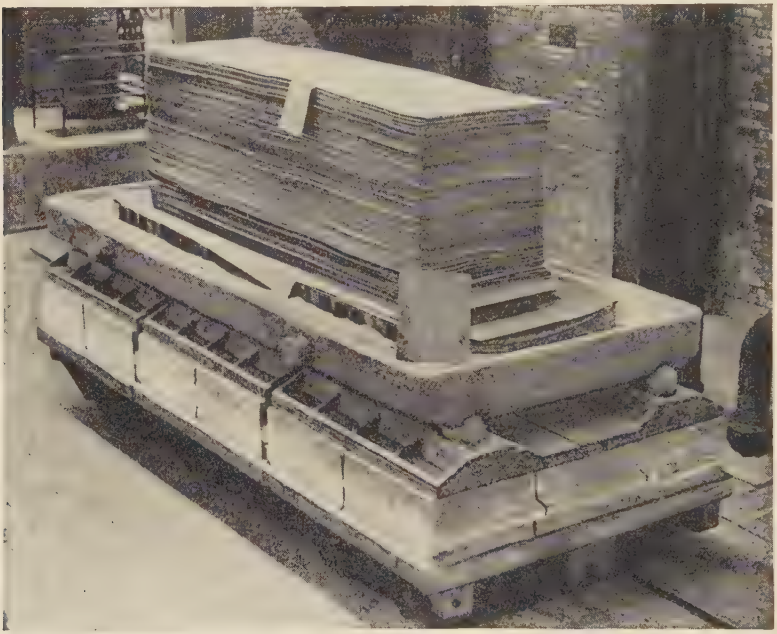

FIG. 234.—Car for continuous annealing furnace.
Note annealing bottom on top of ball race.

frames butt against each other they must be reasonably tight. This latter feature is usually obtained by a tongue-and-groove effect in the refractory material on top of the metallic car bottom. The tongue is very clearly visible in the illustration, Fig. 234. Close observation of Fig. 233 likewise reveals a tongue-and-groove design in the refractory material immediately above the metallic car bottom. In furnaces with open ends (under the cars) the cars should also be reasonably tight on their sides, and in this there lies a difficulty. The sand seal which is so commonly used with

the ordinary car type of furnace will not do in a continuous furnace, because the sand would be continually but irregularly transported towards the discharge end. In kiln furnaces carrying temperatures not exceeding 1600° F. no tight fit is made between the sides of the car and the sides of the furnace. Instead, the ends of the furnace are closed, and projections of the furnace wall extend beyond the sides of the car bottoms in such a way that no direct radiation can reach the space under the car from the furnace room or heating chamber proper. The walls of the chamber in which the bottom of the trucks operate are often cooled by cold air which is blown through steel tubes, and which absorbs what little heat is transmitted from the top by conduction. The shafts or axles of the cars usually operate in roller bearings. This design works out very well, because the closed furnace ends prevent circulation of gases from the space above the car to the space below the car.

Continuous car-type furnaces for temperatures around 2200° F. offer much greater difficulty. The cars and the space under them must be designed to take care of scale and slag. A method of slag disposal is clearly shown in Fig. 233. On account of the open construction under the cars, required for the removal of the slag, there is a strong tendency to air circulation between the space under the cars and the heating chamber. In the furnace shown in Fig. 233 an attempt has been made to provide tightness by the combination of a water seal and an auxiliary sliding seal between spring-pressed pipes and the refractory material of the car. This combination may be studied by reference to Fig. 199, in which the car used in Fig. 233 was illustrated. It will be noted that above the water seal there is a series of pipes which are held by springs against the refractory material of the car, and which keep radiant heat away from the water trough. It is evident that the car can neither enter nor leave the water seal horizontally, because the water would run out of the trough if the ends were opened. To make the use of a water seal possible in a continuous furnace the car is made to enter and leave on an incline, moving downward as it enters and upward as it leaves, as shown in Fig. 233.

The trials and tribulations experienced with car-type conveyors for forging and rolling temperatures are such that they are used in a few exceptional cases only.

Monorail Conveyors.—For partial heating, that is to say, for

processes in which only part of the piece is to be heated, as practiced, for instance, in brazing work, monorail conveyors are quite common. The monorail is out in the open, and the piece to be heated hangs down into the hot zone of the furnace. The same type of conveyor is also used very extensively in japanning ovens. In the latter, the material to be coated is dipped into a solution, removed from it, and then subjected to a current of hot air in an

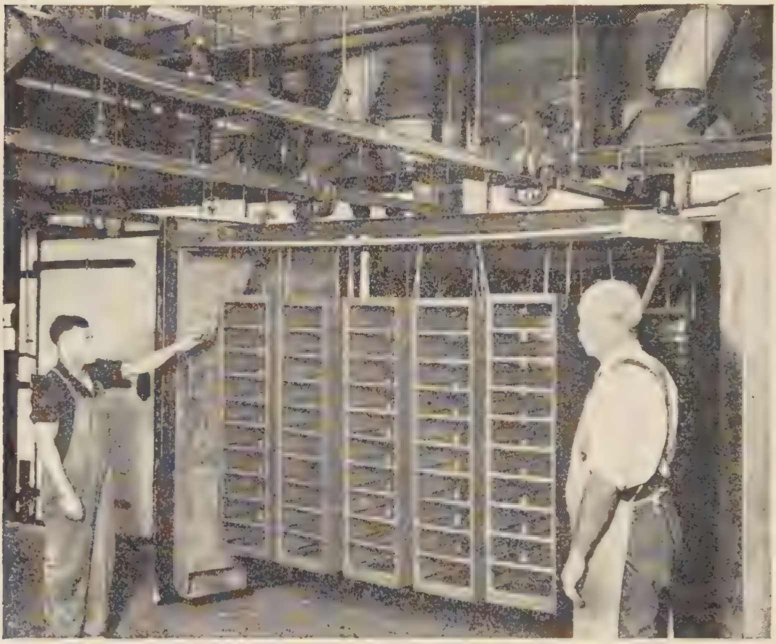

FIG. 235.—Monorail conveyor used in connection with a japanning oven.

oven, at a temperature not exceeding 400° F. For this purpose the monorail conveyor is very well adapted. Its use in such work is shown in Fig. 235. The figure is so clear, and monorail conveyors are so well known, that no comment is needed.

Special Conveyors.—For mass heating of special shapes, such as hack saws, knife blades, and flexible plates such as tin-plate, very ingenious machines and conveyors have been invented. While they are most interesting to the specialist in a given field, they involve very few new principles beyond those already

enumerated here. Besides, a description of all these special conveyors would be very long and would exceed the limits of a more or less general treatise on furnaces. For that reason they are not described here.

Heating Stock Acting as its Own Conveyor.—Material such as wire, chains, long strips, etc., can be towed through a furnace continuously. This principle is very generally utilized in annealing and normalizing furnaces for wire. Beyond the furnace, there are coiling machines, which pull the wire through the furnace, no matter whether the latter be of the open type, of the muffle type, or of the lead-pan type. This method of conveying the material through the furnace is almost automatic, but can never be made wholly so, because, at the end of one coil, the beginning of the next coil must be spliced in such a way that the two parts of the

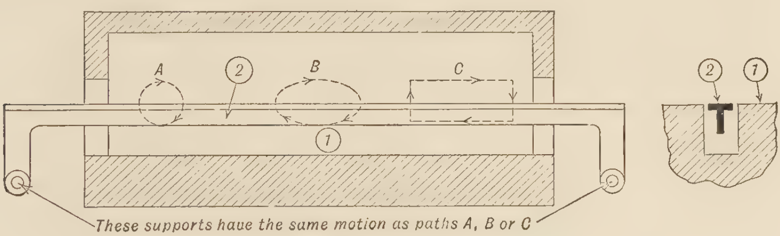

FIG. 236.—Diagram, illustrating action of rocker-bar conveyor.

wire will not pull apart. Attention of the operators is required for this purpose; and a great deal of extra work results if they forget to connect the two coils properly, because in that case it is necessary to thread the new wire all the way through the furnace, a job which consumes a great deal of time and requires skill.

Rocker-bar Furnaces.—Next to chains, the method of transporting material through furnaces by means of rocker bars has appealed most strongly to inventors and designers. The principle underlying this method is illustrated by the diagram, Fig. 236. In this illustration (1) denotes a fixed hearth, while (2) represents a bar which makes any one of the motions indicated by the paths *A*, *B*, or *C*. By any of these motions material resting on the hearth is picked up, is carried forward a certain distance, and is then deposited farther along the hearth, while the rocker bar (2) disappears below the hearth, and returns to its original position. What has been said above with regard to the applicability of

chains for conveying purposes as a function of furnace temperature can be repeated for rocker bars. As long as the furnace temperature is so low that no scale is formed, the rocker bar, which cuts up the continuity of the hearth very much, is well suited to transporting materials through a furnace. As soon as the furnace grows so hot that scale is formed it becomes rather difficult to keep the scale from dropping in between the hearth and the rocker bar, jamming there and causing an endless amount of trouble. If the furnace becomes so hot that the scale and the

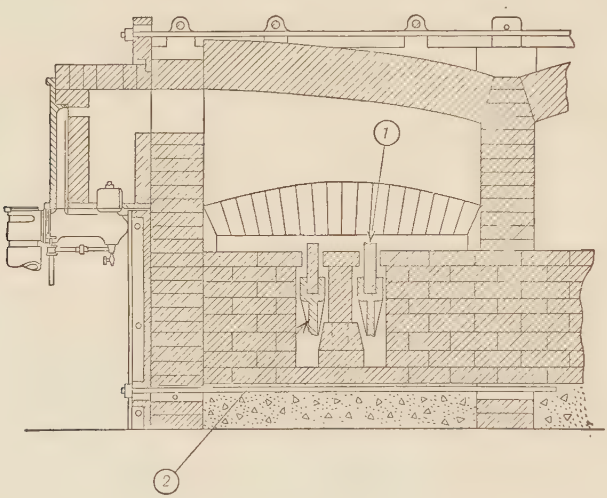

Fig. 237.—Cross section through furnace of the rocker-bar type.

furnace bottom unite in the formation of a slag, the operation of the rocker bar becomes well-nigh impossible.

Even with a low furnace temperature the disappearing rocker bar is by no means immune from troubles. Furnaces are always operated with a slight pressure, and the products of combustion tend to work into the driving mechanism of the rocker bars. But the bar and its operating mechanism must be kept cool so as to prevent warping. In consequence, the hearth is frequently colder than the walls or the roof. Furthermore, irregularities in the hearth or in the motion of the two sides of the bars cause the stock to move off to one side. Repairs to the driving mechanism are slow and costly. Flow of heat into the cold mechanism affects fuel economy unfavorably. If the rocker bars are covered with

refractory tiles the holding of the latter in the bar and the prevention of catching between the moving tile and brick hearth present difficulties. For all of these reasons the rocker-bar furnace has been more popular with inventors than with its users. It may be stated, however, that well-designed and well-operated rocker-bar furnaces are quite successful at a temperature of 1400° F. If a rocker-bar furnace is to be free from trouble the above-mentioned facts must be very carefully taken into account

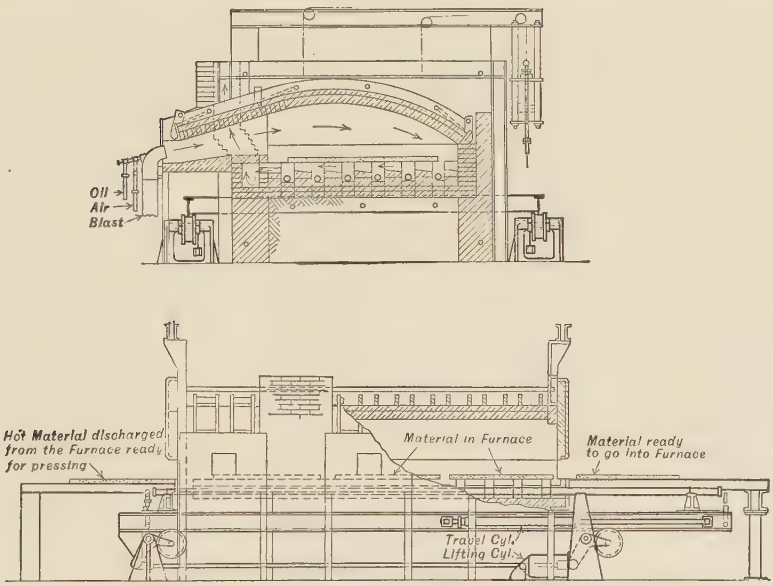

FIG. 238.—Rocker bar furnace for heating plates. The rocker bars travel through a rectangular path and are operated by two hydraulic cylinders.

by the designer and the builder of the furnace and by the man who operates it. A cross section through a furnace in which the designer tried to take care of some of these objections is shown in Fig. 237. Refractory members (1) are held rather rigidly in metallic beams (2). Brick edges of the hearth project sufficiently far to protect the underlying metallic beams from too much direct radiation from the furnace interior. The beams (2) are moved by eccentrics located at both ends and outside of the furnace. There is sufficient space below the beam ends to allow some accumulation of scale, and yet there is not much room left for circulation of air

or of products of combustion between the space under the beams and the heating chamber.

A modern rocker-bar furnace, which is used for heating plates for press work, is shown in Fig. 238. In this design attention was paid to overcoming most of the difficulties which were cited. The motion of the rocker bars corresponds to path C of Fig. 236. The rocker bars consist of water-cooled pipes which drop into grooves between piers on the hearth. The products of combustion

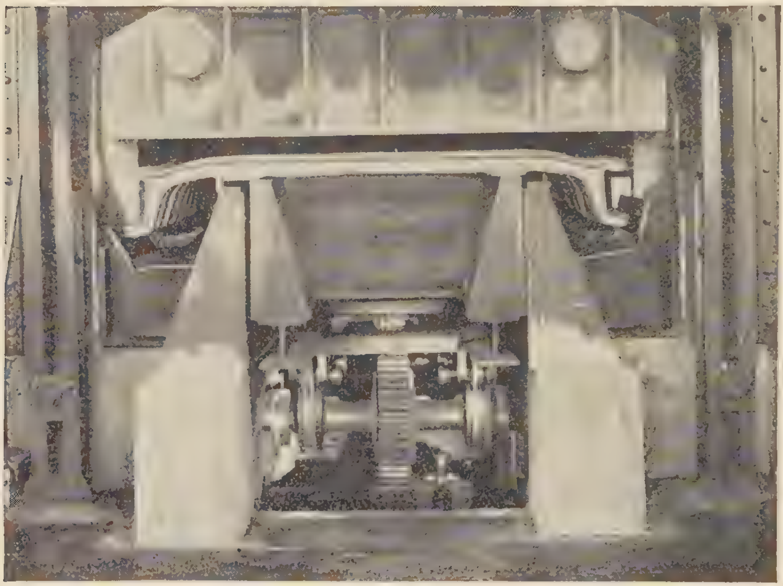

FIG. 239.—Charging end of a rocker-bar furnace for heating axles.

heat the plates from the top and from the bottom. Furnaces of this type have been built in lengths from 12 to 25 feet.

A very good idea of the appearance of the mechanism connected with a rocker-bar furnace may be gained from Fig. 239, which is a view of the charging end of a furnace for heating axles. The wide flanged I-beams which carry the moving hearth are plainly visible.

Vertical Conveying.—The characteristic feature of the conveying systems described in the previous sections of this chapter is that the material is conveyed through the furnace in a prac-

tically horizontal direction. In contrast with these arrangements, vertical conveying has been resorted to in a few instances. Figure 240 diagrammatically illustrates a method of conveying which is used for annealing small material. The latter is shoveled in at the top and moves downward by gravity at the rate at which heated and annealed material is removed from the bottom. The removal at the bottom may be accomplished by shoveling or raking, or else by means of a slowly moving conveyor. It is easily seen that the method illustrated in Fig. 240 has its limitations. It can only be used for heating stock that will move vertically without trouble, and will not be injured by the weight of the overlying charge. The conveying system in question is used particularly for the annealing of small castings, pipe fittings, and the like.

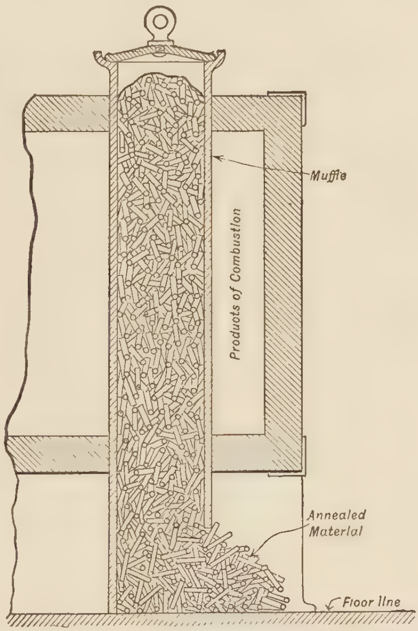

FIG. 240.—Vertical conveying through annealing furnace.

Another method of vertical conveying is illustrated in Fig. 241. According to this scheme two sets of scoops are alternately tilted clockwise and counter-clockwise, so that one set of scoops discharges while the other one receives. By this arrangement any material which is charged at the top gradually works its way downward towards the discharge chute. The scoops, as well as the axles supporting them, must be made of material with excellent heat-resisting characteristics. The supporting axles must be made quite strong. Furthermore, the furnace must be made narrow enough at right angles to the plane of the paper to prevent deflection of the containers and of their shafts under the influence of the weights of the parts, of the impact of the dropping material, and

of the temperature of the furnace. If these precautions are carefully observed, the tilting pans will doubtless work to satisfaction. Incidentally, it may be remarked that electrical heat is employed in the furnace shown in the illustration.

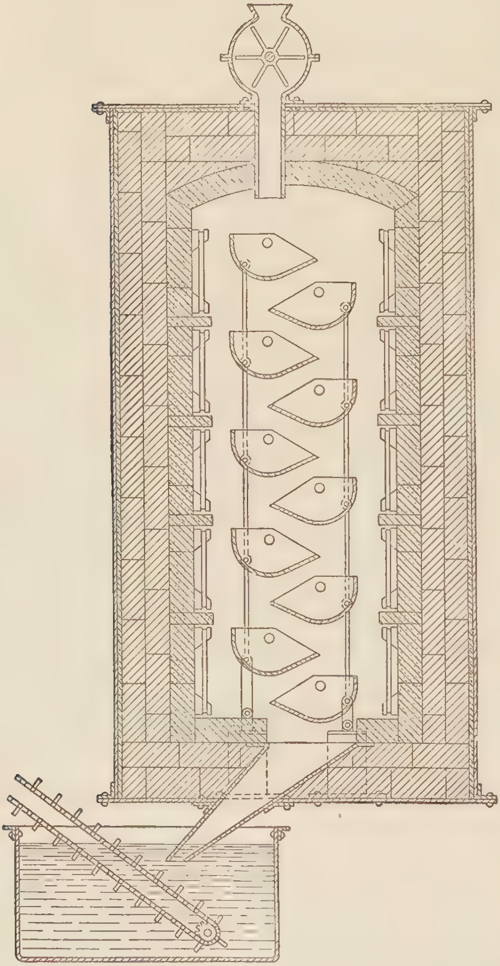

FIG. 241.—Automatic heat-treating furnace with vertical conveying of charge.

Transporting by Circular Motion.—In many respects circular motion is much more convenient than straight-line motion, a fact which is acknowledged in machining operations and in many other manufacturing processes. A study of the methods of circular conveying to be described in this section will prove that circular transportation indeed deserves to be used more widely than it has been used in the past. It will doubtless find its way into furnace practice on an increasing scale.

The most natural step to take in the application of rotary motion to furnace design is that of providing, within the furnace, a rotating table or rotating hearth, as shown in Figs. 242, 243, and 244. In the use of a rotating table or rotating hearth many interesting facts are to be noted. Since any point on the table

describes a purely circular motion, its path continually returns within itself, and a piece lying on the hearth is never discharged unless it is removed by some external means. Figure 242 illustrates a method of charging the rotating hearth from its outer periphery. The discharging can be accomplished either by stopping the hearth and applying the pusher or else by providing scrapers close to the hearth for the purpose of crowding the material towards the inner periphery. The illustration indicates a method of discharging the heated material directly from the interior of the furnace into a quenching tank. In by far the greater number of rotating-hearth furnaces, both charging and delivery are effected at the outer periphery. A furnace for small work, built upon this principle, is illustrated in Fig. 243. The charging door and the delivery door are close together. The conveying of the material through the furnace is automatic, but

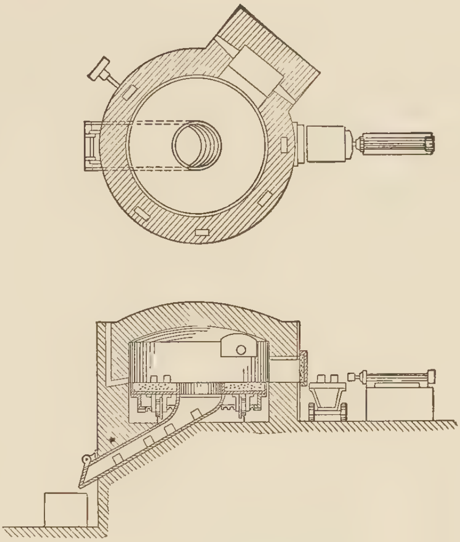

Fig. 242.—Diagrammatic illustration showing principle of furnace with rotating hearth.

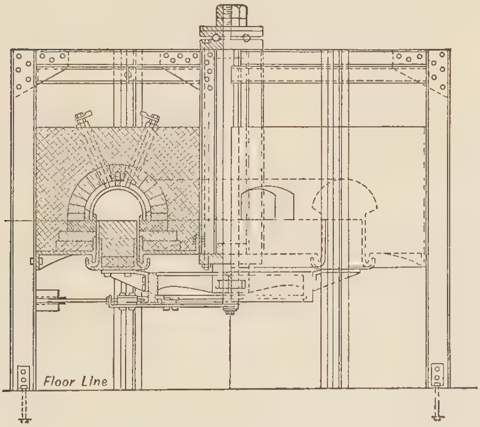

Fig. 243.—Furnace with rotating table for light work.

the delivery is not. The material must be placed upon the hearth by the operator, and must also be picked or raked off the hearth by him, after the piece has made almost one revolution in the furnace. It will be noticed that the furnace shown in Fig. 243 is electrically heated. The "dough-nut" type is equally well suited for use with fuel-fired furnaces, as may be judged by a study of Fig. 244, which likewise illustrates a furnace with a rotating hearth. In this furnace the hearth proper consists of close-fitting segments of a heat-resisting alloy, which rest on fire-

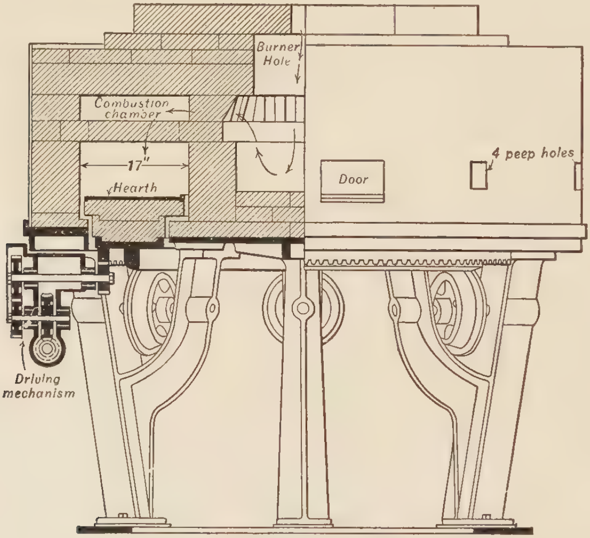

FIG. 244.—Centrally fired furnace with rotating hearth.

bricks. The latter, in turn, are supported by a steel ring, resting upon rollers. The speed of rotation can be varied between twenty minutes and one hour per revolution. Combustion takes place in a central core, from which the gases pass out radially into the furnace, escaping from it through the front doors. By tilting the burner slightly it is possible to divert most of the hot gases to the side where the cold work enters the furnace; this arrangement tends to equalize the temperature above the hearth.

While the last three furnaces shown are particularly suitable for small work it must not be thought that rotating-hearth furnaces are limited to such work. On the contrary, they have been built

in large dimensions. This fact is illustrated by Fig. 245, which represents a furnace for hardening automobile gears in containers. It is well known that temperatures of over 1700° F. are required for hardening. In this particular hardening furnace one revolution of the hearth takes from six to ten hours. The speed reduction from a high-speed motor down to one revolution in ten hours is very extreme. It is obtained in this case by a ratchet motion in combination with gearing. By adjustment of the lever arm on the driving ratchet, the angle through which the table turns for each stroke of the ratchet lever is varied. Strictly speaking, this would tend to make the motion of the table jerky, but, on account of the extreme slowness of motion, no jerkiness or discontinuity whatever is noticeable. In a large furnace, uniform bearing of the table on all of the rollers is necessary. For that reason, in the furnace illustrated in Fig. 245, a walk-way has been provided underneath the table so that the attendants can inspect the contact between the rollers and the revolving hearth at regular intervals. Several furnaces of this type replaced in-and-out or batch-type furnaces at a gear works. The rotating-hearth furnace showed 100 per cent increase of production for a given floor space, 45 per cent saving in labor, and 20 per cent saving in fuel. The success of this furnace dispels the notion that large furnaces with rotating hearths are bound to fail. It may be stated positively, however, that their construction requires considerable mechanical engineering skill in addition to a knowledge of bricklaying.

The straight-line continuous furnace has, without a doubt, the great advantage of moving the material through the shop in a logical manner, maintaining a constant direction of travel; but it also has the disadvantage that irregular shapes cannot be moved through it except on cars or in trays or on chains. The objection that a rotating hearth does not move the material through the shop in the logical manner is not necessarily valid, as will be seen by a study of Fig. 246. The material can still be made to travel through the shop in a straight line by the method there indicated, and departs from it only at the place where the furnace is located. This arrangement causes no trouble, except where several sets of material are moving through the shop in parallel lines. In that case the round furnace is likely to result in some waste space.

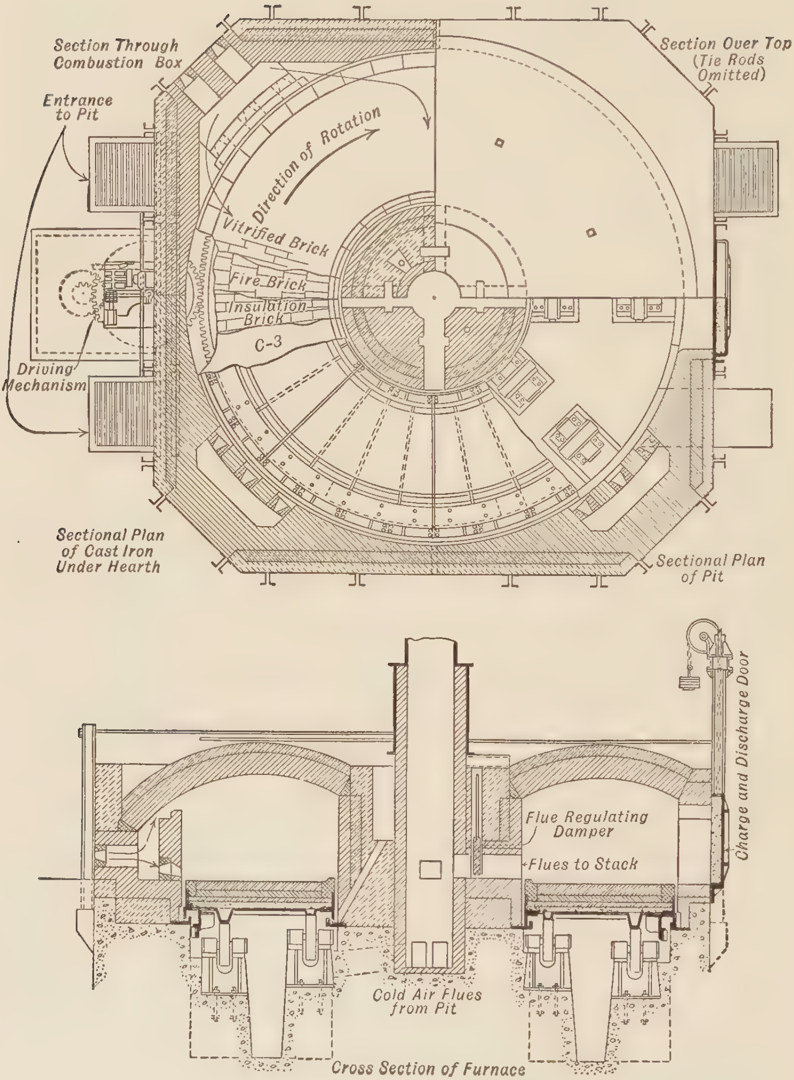

FIG. 245.—Large furnace with rotating hearth for hardening gears in containers.

Like so many other furnaces with automatic conveying devices, the rotating hearth is limited to temperatures at which no slag is formed. If slag formation occurs, the slag runs along the sides and gets into the joints between rotating and fixed parts or even into the driving mechanism, causing endless trouble. If automatic discharging devices, in the shape of scrapers, are to be used in connection with a rotating hearth, the temperature should be low enough for the use of a metal covering on top of the refractory hearth material, so that there may be no projecting bricks on which the scraper, in conjunction with the charge, could catch and cause tearing up of the whole outfit.

The furnace with rotating hearth offers the great advantage, in addition to labor-saving features, that the hearth always remains in the heat. In this respect, it differs from most of the conveyors used in straight-line motion furnaces. In consequence of this advantage, the heat which is stored up in the hearth is not lost at every revolution, as it is in chain conveyors or in moving cars, but is retained in the hearth. Furthermore, disintegration due to repeated heating and cooling does not take place.

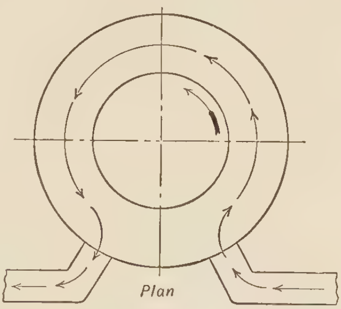

FIG. 246.—Diagram of motion of material through furnace with rotating hearth.

There is one type of rotating furnace which does not share this advantage. This is the type in which the hearth is a stationary ring, over which the furnace slowly creeps. Such a furnace has been built for heating long pieces which could not very well be put in or taken out through the door of an ordinary furnace with rotating hearth. In the furnace in question the length of the furnace covers only part of the length of the annulus. The furnace rests on rollers and moves about slowly, successively covering different parts of the ring-shaped hearth. It is not likely that furnaces of this type will ever become popular.

Other Circular Conveyors.—The advantages offered by transportation due to circular motion are not limited to furnaces with rotating hearths. On the contrary, they are found in many different types of conveyors. A few examples will illustrate this

statement. Figure 247, for instance, shows a section through a ring-shaped annealing furnace; the material which is to be annealed is carried by brackets which extend from a circular, centrally located table, through a slot in the inner periphery of the furnace, into the heating chamber. The ring forming the furnace is not complete; about one-eighth of the circumference

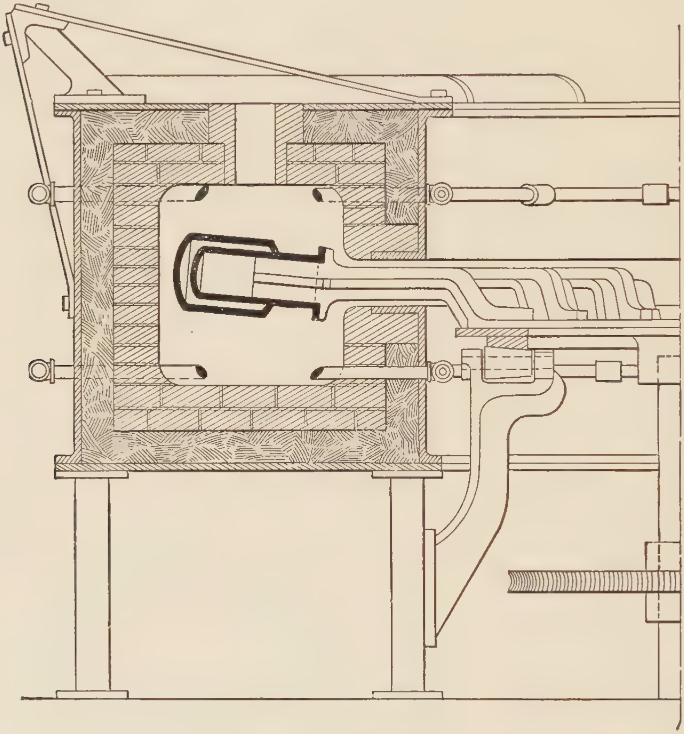

FIG. 247.—Furnace with rotating conveyor for annealing cylinders of automobile engines.

is not covered by brickwork, but is out in the open. In this open section the attendant can remove the heated and annealed material from the prongs or brackets, and can place other material to be annealed on the prongs vacated by the pieces which he has just removed. The furnace in question is shown as being fuel-fired, but the same feature can be applied just as well to an electrically heated furnace.

While the annular, or circular, furnace shown in Fig. 247 is provided with a slot in its inner periphery, many similar furnaces are built with the slot either in the upper or in the lower bounding surface. The material to be heated then either hangs down into the furnace from a circular conveyor operating above the furnace, or it projects upward through a slot into the furnace, from a circular conveyor located below it. In quantity heating of chain link blanks, knife blades, and similar material, this type of mechanical conveyor is very extensively used.

Helical Conveying.—In the practice of cement manufacture, and in metallurgical practice, material is frequently conveyed through furnaces or kilns by means of a motion rather akin to that of the helix. The conveyors are inclined drums into which the material is charged at the top. The rotation of the drum continually tends to carry the material up on one side, in a plane at right angles to the axis of the drum. The material climbs up on the side a certain distance or arc only, the size of which depends upon the coefficient of friction between the material of the tube and the material to be heated. It then drops back not in the same plane in which it was raised, but rather in a vertical plane. In consequence, the material passes from the top of the inclined kiln to the bottom with a sort of zigzag motion. The speed with which it traverses the kiln depends upon the inclination of the drum, its speed of rotation, and upon the coefficient of friction between the material of the drum and the charge. The length of a drum cannot be changed easily, and since we have no control over the coefficient of friction between the charge and the wall material, adjustments are commonly made either by varying the inclination of the drum or else by adjusting its rotative speed. In some cases both elements are adjusted.

From the above description of the zigzag motion it is evident that the term "helical motion" is somewhat of a misnomer, and yet it probably describes the action of the conveyor better than any other term would do. It should be noted that in certain other conveyors of this same general type, to be described below, the motion is much more nearly helical. A furnace embodying the motion which was described in the last paragraph is illustrated in Fig. 248. In accordance with the principles stated above, the inclination of the revolving drum can be adjusted by means of the handwheel, working through a worm wheel set and a

pinion and segment set. Incidentally, the illustration shows how the heated material is automatically discharged into a quenching tank, and is automatically removed therefrom by means of a chain and sprocket conveyor. Some complications are introduced by the necessity of transmitting motion to the revolving drum through the axis of the pivot point, so that motion may be correct at any angle of tilting of the drum. This

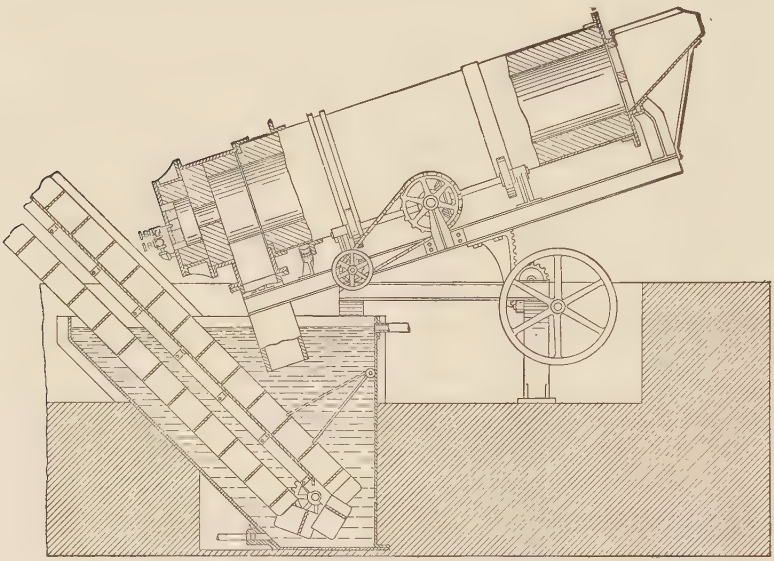

FIG. 248.—Rotating-drum furnace.
Note adjustment of inclination.

could obviously be avoided by placing the motor directly on the frame of the drum.

The smooth drum, as illustrated in Fig. 248, is apparently not suited to conveying round material such as balls or rollers. Material of that description rolls through the inclined furnace along the bottom, without being carried up along the sides and dropping back in zigzag fashion, as explained above. If easily rolling material is to be conveyed, it is preferable to use a horizontal and truly helical conveyor, that is to say, a drum inside of which there is a screw thread. This principle, which is likewise a very old one in the art of metallurgy, is illustrated in Fig. 249. In this type of conveyor the rate of progress of the heating stock through

the furnace is definitely given by the pitch of the helix and by the rotative speed of the drum. The quantity of material sent through the furnace depends upon the rate of feeding that material into the drum. The furnace illustrated in Fig. 249 is equipped with a supply hopper (shown at the left-hand side of the illustration) which automatically feeds a certain amount of heating stock into the drum at a pre-determined and adjustable rate. It will be seen that the furnace is wholly automatic. For that reason it has become very popular for the heat treating of small articles.

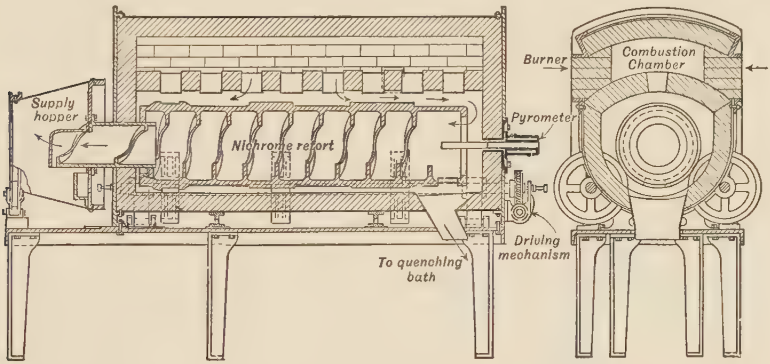

FIG. 249.—Automatic furnace of the revolving-drum type. The charge is transported by helical motion.

It must not be thought that the field of the furnace just described is unlimited. If a piece of material can ride astride one of the ribs it will be carried around without progressing axially. This statement, in connection with the fact that the material of the retort, no matter whether it be metallic or refractory, loses its strength at high temperatures, assigns a definite field to the furnace. This field is quite large, however, and the furnace is adapted to handle, either for annealing, hardening, tempering, or bluing, any pieces of small and uniform dimensions (not too oblong) in either brass, copper, steel, or other metals, such as eyelets, ferrules, buttons, caps, cups, coin blanks, steel balls, saw teeth, tacks, screws, rivets, rings, certain types of springs, nuts, punchings, in fact any small pieces which will travel freely and pass through the openings without choking them.

It may incidentally be noted that a revolving drum provided with internal helical ribs need not be inclined, whereas a

smooth drum must be inclined in order to produce a forward and downward motion of the charge.

This concludes the description of the principal types of conveyor mechanisms used for furnaces. It is needless to say that conveyors are also used for bringing the material to the furnace and for removing it from the furnace. However, the present volume is not a treatise on automatic conveying machinery in factories. For that reason the conveyors outside of the furnace, no matter how interesting they may be, cannot be discussed or described here in detail.

Devices for Comfort and Convenience.—There exists, however, another phase of furnace construction which, although not directly labor-saving, must be discussed here because it saves labor indirectly, by increasing the convenience and comfort of the various workmen around the furnaces. It is a well-known fact that men who are not exposed to excessive heat or to obnoxious fumes will do more work in a given time than those who are so exposed. A brief discussion of devices for improving working conditions around the furnace may, for that reason, not be amiss.

The equipment in question is used more particularly in connection with fuel-fired furnaces than with electrically heated furnaces. The latter produce no fumes, and are always very well insulated, because of the high cost of electrical heat.

It is quite customary to discharge the products of combustion of gas or oil directly into the workshop. While this procedure is permissible for a small furnace in a large, well-ventilated shop, it is not advisable in other cases. Hoods or canopies, which collect the fumes and discharge them through the roof, are much to be preferred. These hoods assume various shapes, depending upon the type of furnace which they serve and upon the shape of the building in which they are located. A diagrammatic sketch of a furnace with hoods at both ends is shown in Fig. 250. The furnace in question is intended to discharge all of the products of combustion through the door openings, so that the room in which the furnace is located is filled with the fumes unless they are taken away as indicated. Hoods for carrying away the products of combustion should be considered at the time when the furnace installation is planned, because that consideration may influence the location of the furnace in the factory. It is quite evident that hoods carried up through the roof will frequently interfere with

crane operation, unless the furnace has been properly located with a view to avoiding such interference. There is no doubt that interference with crane operation is the principal reason for the limited application of furnace hoods. Underground flues and stacks should take the place of hoods if the latter interfere with crane operation. Even if stacks are provided for carrying away products of combustion a hood will often be found convenient, because industrial furnaces work with a slight pressure in the heating chamber. If the door must be opened frequently or kept open all the time, the gases which are constantly being discharged will fill the working room unless they are carried off by a hood which leads up to vents in the roof.

Hoods are a positive necessity on furnaces that discharge poisonous fumes, such as cyanide vapors. In addition to providing

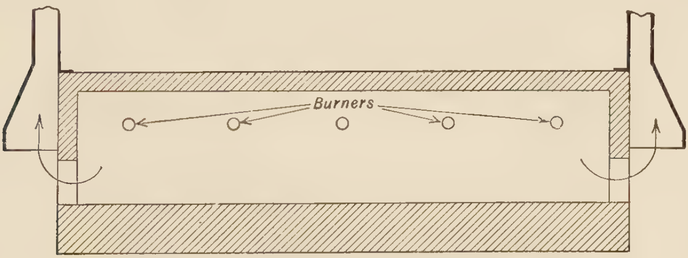

FIG. 250.—Arrangement of fume-collecting hoods.

hoods, engineers usually locate cyanide pots on the top floor of the factory in well-ventilated rooms, and provide fresh air by means of fans or blowers, the discharge of which is directed towards the furnace attendants.

Bolt-heading furnaces and other furnaces for drop forge work are particularly trying on the operators, because all of the products of combustion are discharged through the constantly open doorway directly into the face of the attendant. Water-cooled shields hung in front of the doors are a very good addition to such furnaces. The water-cooled shields are hung sufficiently far away to allow most of the products of combustion to rise between the shield and the furnace proper. Water is discharged from a spray pipe against the top of the shield and is collected by a trough at the bottom. The space between the shield and the furnace can also be connected to a hood for carrying the products of combus-

tion away. Pipes for preheating combustion air have been placed in the space between the shield and the furnace, as shown in Fig. 251. On account of the great velocity with which the products of combustion issue from the door opening, they tend to rush into the workroom, instead of going up into the space between the shield and the furnace. An air pipe laid underneath the bars in front of the door, and provided with upwardly directed openings, helps to blow the products of combustion in the proper direction. This air pipe is likewise indicated in Fig. 251. A similar purpose is served by chain doors, which were described in Volume I. In

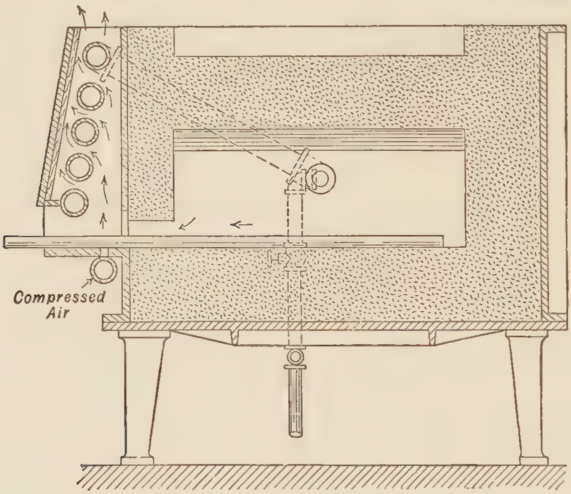

FIG. 251.—Drop-forge furnace with protecting shield and air blast.

several factories chain doors were tried and were discarded because the heating stock caught on the chains and caused trouble. The regular makers of chain doors have had experience with such conditions and, in all cases where the material might catch in the chains, equip the bottom of the chains with pipes instead of links. It is scarcely possible that anything would catch on the round pipes which form the bottom of the chain doors.

In Volume I the statement was made that, as far as strength and durability are concerned, water-cooled doors are not necessary on heating or annealing furnaces. They are, however, occasionally applied for the sake of the convenience and comfort of the attendants, although their use probably results in a somewhat

increased fuel consumption. A home-made and very effective water-cooled door is shown in Fig. 252. It will be seen that this door consists of a steel casting to which a steel plate is welded. The only difficulty in this construction consists in getting a casting which is sufficiently free from porous places to hold water.

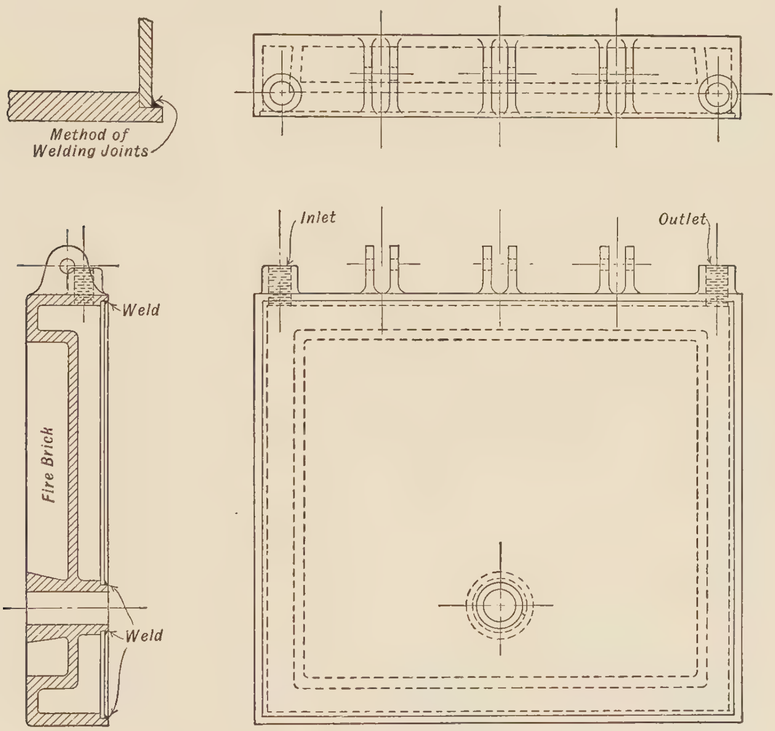

FIG. 252.—Water-cooled furnace door.

In industrial work there are several types of furnaces in use in which the nature of the operations is such that men must work in front of a constantly open doorway. In pipe welding, for instance, men must continually observe the condition of the pipe blank and must push it out into the welding rolls at the very instant the skelp has been heated through to a white heat. In that case neither a chain door nor any similar device can be employed. For protection, the men wear masks in front of their faces, and are cooled by fans. There are now large fans on the

market for this purpose, under the name of "man coolers." In some furnace work conditions arise in which an attendant must stand at a hot and uncomfortable spot for a long time; air is then blown through conveniently located ducts and is so directed as to give the greatest possible comfort to the furnace attendant.

Where the heated material is continually dragged over the floor plates near the furnace, as in sheet mill practice, the floor becomes uncomfortably warm. Water-cooled floor plates are often provided in such places to reduce the discomfort of the workmen.

CHAPTER VI

CRITICAL COMPARISON OF FUELS AND OF FURNACE TYPES

Basis of Comparison.—Whenever a new furnace is to be installed it becomes necessary to select the best type of furnace and the most suitable source of heat energy. For a few specific conditions this problem will be discussed in detail in Chapter VII, and the reasons for the adoption of certain fuels and furnace types will be given. The present chapter compares fuels and furnaces on general principles, without their application to given plant conditions, and is, to that extent, preparatory to the next chapter.

Comparisons are odious, but they must be made in order to secure the survival of the fittest with a minimum of expense and trouble to users and sellers of fuels and furnaces. The whole subject is a very delicate one, because those who make their living by building and selling furnace equipment may resent unfavorable comparisons. For that reason apparent and obvious facts only are cited, and personal opinions have been omitted. In comparison with other chapters, the present one and Chapter VII will appear rather unscientific and filled with generalities; but it is true that in all walks of life we can be truly scientific in a moderate degree only, and that we must make important decisions on the strength of judgment derived from a mass of more or less incoherent information.

The following tabulation gives an approximate idea of the number of combinations which are possible in furnace work. It will be noted that five subheadings have been selected: namely, Source of Heat Energy, Utilization of Waste Heat, Method of Heat Transfer, Method of Handling Materials, and Method of Heat Application. It is proposed to compare critically the elements under each of these five subheadings:

TABLE XXIII

CLASSIFICATION OF ELEMENTS FOR CRITICAL COMPARISON OF FUELS AND FURNACES

Source of Heat Energy	*Utilization of Waste Heat*	*Method of Heat Transfer*	*Method of Handling Materials*	*Method of Heat Application*
Electricity	In heating stock (preheating of stock)	Open chamber		
Gaseous fuel:	In waste-heat boilers	Muffle	Batch type:	Partial heating
Natural gas		Salt or lead bath	Fixed hearth	Heating stock is electrical resistor
City gas	By preheating of fuel or air:		Pit furnaces	Underfired type
Coke-oven gas	Regeneration		Car-bottom type	Sidefired type
Raw producer gas	Recuperation			Overfired type
Clean producer gas			Continuous type:	Recirculating type
Carbo-gas			Pusher type	
Water gas			Conveyor type	
Blast-furnace gas			Drum type	
Oil gas			Rotating hearth	
Liquid fuel:				
Kerosene				
Light fuel oil				
Heavy fuel oil				
Tar				
Solid fuel:				
Anthracite Coke Coal Lignite } on the grate				
Powdered coal				

Since any element in any one of the subdivisions can be combined with any other element in the other subdivisions, the number of possible combinations and of furnace types runs into the millions, as a comparatively brief mathematical calculation shows. The almost infinitely large number of possible combinations has led to the decision to compare critically only the elements or possibilities contained within each of the subheadings.

Sources of Heat Energy; Their Influence upon Furnace Design and upon Cost of Industrial Heating.—The sources of heat energy fall into two broad subdivisions, namely, (1) heat energy derived from the combustion of fuel in the furnace (or in an adjacent combustion chamber), and (2) heat energy derived from conversion of electrical energy. The general properties of fuels were discussed in detail in Chapter I. In the present chapter their effect upon the production of perfect heated material, and upon the cost of such heating, will be discussed in greater detail.

The cost of fuel or other source of heat energy is, in many instances, an exceedingly small fraction of the total cost of the manufactured product and a minor fraction of the heating costs. In such cases the effect of the form of energy upon the quality of the finished product is most important, and the unit cost of energy per B.t.u. is not a matter of consideration. But there are other cases in which the fuel cost is a large item in the total cost of heating, and in which the effect of the type of fuel upon the final product is negligible. In such cases cheapness of fuel per unit of heat is the deciding factor. The following tabulation may be used in comparison of fuels and other sources of heat energy:

GASEOUS FUELS.

(*a*) **Natural gas.**—Where available, it is a most excellent fuel for all-round heating purposes.

Advantages:

(1) Heating value is high.
(2) Pipe mains may be small, owing to (1).
(3) Gas can be burned efficiently.
(4) High flame temperatures are easily obtainable.
(5) Accurate flame control is possible.
(6) Accurate atmosphere control is possible.
(7) Uniform quality of product is possible.
(8) Damage to product is slight (few rejections of finished material).

(9) Furnace installation is simple.
(10) Cost of furnace installation is low.
(11) In many districts fuel cost is low.
(12) Fire risk is low.
(13) Plant can be kept clean without difficulty.
(14) Cost of upkeep of furnace may be kept low.
(15) Labor cost is low (no handling of fuel or ashes).
(16) Oxidation of heated material can be kept low.
(17) Furnace is made ready for use by opening a valve.
(18) No fuel-preparation plant is needed.

Disadvantages:

(1) Supply is unreliable in many sections of the country, particularly in cold weather.
(2) Supply is diminishing.
(3) Cost is gradually increasing, owing to (1) and (2).

(*b*) **City gas.**—This is especially adapted to small-sized and medium-sized, high-grade, high-temperature work, but is useful in all cases where heat is to be utilized economically.

Advantages:

(1) Heating value is high.
(2) Pipe lines may be small, owing to (1).
(3) Gas can be burned efficiently.
(4) High flame temperatures may be attained.
(5) Accurate temperature control is possible.
(6) Accurate control of furnace atmosphere is possible.
(7) Uniform quality of product is possible.
(8) Minimum damage to product (few rejections) is possible.
(9) Furnace installation is simple.
(10) Cost of furnace installation is low.
(11) Plant may be kept clean without difficulty.
(12) Fire risk is low.
(13) Low cost of furnace maintenance is possible.
(14) Labor cost may be kept low (no handling of fuel and ash).
(15) Scaling of heated material can be kept low.
(16) Furnace is made ready for use by opening a valve.
(17) No fuel-preparation plant is needed by the user.

Disadvantages:

(1) Fuel cost is very high.
(2) Gas is available only in cities with gas plants.

(*c*) **Water gas.**—This is most valuable for high-grade, high-temperature work, in large-scale heating and welding operations, especially those using high flame temperature with cold air.

Advantages:

(1) Heating value is high.
(2) Pipe lines may be small, owing to (1).
(3) Gas can be burned efficiently.
(4) Very high flame temperatures can be attained.
*(5) Accurate temperature control is possible.
*(6) Accurate control of furnace atmosphere is possible.
*(7) Uniform quality of product is possible.
*(8) Minimum damage to product is possible.
(9) Furnace room may be kept clean without difficulty.
(10) Fire risk is low.
*(11) Scale on product can be kept low.
(12) Gas burns without smoke, even in cold furnaces.

Disadvantages:

(1) Cost of installing a water-gas plant is high.
(2) Installation of furnace plus gas plant is much more complicated and expensive than for oil, natural gas, or city gas.
(3) Fuel for gas producer requires handling.
(4) Ash from gas producer must be disposed of.
(5) Cost of operating labor at producer is high.
(6) Fuel supply is restricted (coke or anthracite required).
(7) Odorless but poisonous gas is a menace to life and health.
(8) Cost of gas per B.t.u. is high (in small plants).
(9) There is danger of backfire due to rapid flame propagation.

(*d*) **Raw producer gas.**—It is the most commonly used fuel for those large furnaces in which close regulation of temperature and of furnace atmosphere is not required.

Advantages:

(1) Cost per B.t.u. is low.
(2) Gas can be made wherever bituminous coal is available.
(3) Operation of gas making is comparatively simple.
(4) Gas burns with luminous flame.
(5) Installation cost is lowest of any artificial gas-making equipment.
(6) Gaseous fuel of this type (made in "integral producer") may be used in small, isolated furnaces.

Disadvantages:

(1) Furnaces must be located close to producers, because the tarry vapors condense and the sensible heat of the gas is lost in long pipe lines.
(2) Gas flues become clogged with soot and tar, and must be burned out at regular intervals.

* These advantages depend upon correct operation of the gas-making plant.

(3) There is difficulty in maintaining gas of constant composition and quality.
(4) It is difficult to keep intelligent workmen in dirty gas house.
(5) Coal must be delivered to producer.
(6) Ashes and clinkers must be removed from producer.
(7) Steam plant is required for furnishing steam to the producers.
(8) Large producer mains, brick lined, are required for carrying the gas from producers to furnaces, to avoid back pressure on the producers. (Does not apply to integral producer.)
(9) Flow of producer gas cannot be measured, on account of dirt in gas.
(10) Screened gas coal is required for best results.

(*e*) **Cold, clean producer gas.**—Efficient use of this fuel is limited to a maximum of about 2000° F., unless regenerative or recuperative furnaces are used. It is useful for installations of large size only.

Advantages:

(1) Gas can be burned efficiently.
(2) Temperature of combustion is low (desirable for furnaces with less than 1600° F. temperature).
*(3) Accurate temperature control is possible.
*(4) Accurate control of furnace atmosphere is possible.
*(5) Uniform quality of heated product is possible.
*(6) Damage to heated product can be kept small.
(7) Life of furnaces is long, if they are properly designed and operated.
(8) Fuel supply is reliable.
(9) Fuel cost is stable.
*(10) Scaling of product can be kept small.
(11) Gas burns without smoke, even if the atmosphere is reducing.
(12) Fuel cost is comparatively low in large installations.
(13) Can be distributed to many small furnaces.

Disadvantages:

(1) Cost of installing gas-making plant is high.
(2) Coal requires handling.
(3) Ashes must be disposed of.
(4) B.t.u. content of fuel is low.
(5) Large pipe mains are required on account of (4).
(6) Cost of operating labor at producer is high.
(7) Installation is more complicated and expensive than with oil, natural gas, or city gas.
(8) Tar made in producers must be disposed of.
(9) Good furnace operation depends upon zeal on the part of gas house operators.

* These advantages depend upon correct operation of the gas-making plant.

(*f*) **Carbo-gas.**—(A mixture of producer gas and of distillation gas, made by a low-temperature carbonization process.) This requires very expensive installation, and is useful for large-scale operations only.

Advantages:

(1) Heating value is higher than that of any other gas made by a continuous process and total carbonization of coal.
(2) Flame temperatures are higher than those of cold, clean producer gas.
(3) By-product recovery is possible.
(4) Smaller pipe mains are required than for clean producer gas, on account of higher B.t.u. content.
(5) Gas can be carried advantageously to a number of small furnaces.
(6) A luminous flame can be obtained.

Disadvantages:

(1) Cost of installing gas-making plant is very high.
(2) Coal must be delivered to producers.
(3) Ashes from producers must be disposed of.
(4) Cost of operating labor at producers is high.
(5) Installation is complicated and requires competent supervision.

(*g*) **Coke-oven gas.**—This gas is, as a rule, only available in combination blast-furnace and steel plants. It is similar to town gas, but much cheaper.

Advantages (available in steel plants only):

(1) Heating value of gas is high.
(2) Gas can be carried in small mains on account of (1).
(3) Gas can be compressed on account of its comparative cleanliness.
(4) High flame temperatures may be attained.
(5) Gas readily lends itself to automatic temperature control.
(6) Correct furnace atmosphere is not difficult to maintain.
(7) Gas is easily distributed to a number of scattered furnaces.

Disadvantages:

(1) Cost of installing by-product coke plant is high.
(2) Gas is available in limited quantities only.
(3) Burners must be specially designed for this gas, on account of its low specific gravity.

(*h*) **Blast-furnace gas.**—This is available in a few steel plants only, for heating furnace work.

Advantages:

(1) It is a good gas to mix with coke-oven gas for the purpose of regulating flame temperatures.

(2) It is also suitable for burning conjointly with tar, for the purpose of conserving tar supply and reducing flame temperatures.

Disadvantages:

(1) Thermal value is the lowest of any fuel gas.
(2) Large pipe mains are required on account of (1).
(3) Flame temperature is insufficient for most heating operations unless gas is preheated.
(4) Gas is extremely poisonous.
(5) It is available in a very few places only.

(*i*) **Oil gas.**—Gaseous fuel made by partial gasification and by partial vaporization of medium (26 to 32 degree Baumé) fuel oils.

Advantages:

(1) This gas has many of the advantages of city gas or natural gas, without being tied to location.

Disadvantages:

(1) Certain grades of oil are required for its manufacture.

LIQUID FUELS.

(*a*) **Fuel oil.**—This is the standard fuel for medium-sized furnaces, except where convenient and cheap gaseous fuels are available.

Advantages:

(1) First cost of installation of furnace and auxiliaries is low.
(2) Fuel oil is convenient to handle. This is particularly true of the lighter oils.
(3) The installation is simple; it is particularly simple and inexpensive for light oils.
(4) Oil may be stored conveniently.
(5) Cost per unit of heat is comparatively low; cost is, as a rule, very low for very heavy fuel oils.
(6) High flame temperature may be attained.
(7) Oil can be had anywhere.

Disadvantages:

(1) Cost of fuel fluctuates, especially for light oils (gas oils).
(2) Furnace temperature is difficult to control automatically, except for a clean oil of constant composition.
(3) Furnace atmosphere is difficult to control automatically.
(4) There is a possibility of damaging heated product, caused by (2) and (3).
(5) Fire hazards are high.
(6) Cost of labor is high on account of (2), (3), and (4).

(7) Life of container boxes is likely to be short as compared with non-oxidizing gas fuel.
(8) Furnaces are more easily damaged than with gas fuel.
(9) Preheated air is required, if reducing atmosphere is to be obtained without excessive smoke.
(10) Careful straining is required.
(11) Correct functioning depends upon untiring attention to burners and to auxiliary equipment.
(12) Heavy oils require recirculating system.

(*b*) **Tar.**—As a rule, tar is available in steel plants only.

Advantages:

(1) Tar burning uses up a by-product.
(2) Tar may be stored conveniently.
(3) It is valuable for mixing with coke-oven gas or blast-furnace gas for producing higher flame temperatures.

Disadvantages:

(1) Fuel is dirty and smeary.
(2) Fine coke particles which it contains cause difficulties with strainers and burners.
(3) Tar must be kept in circulation after being heated, to prevent clogging of pipes.
(4) It is available in a few steel plants only.
(5) Tar flame is very injurious to furnace brickwork.
(6) Other disadvantages the same as with heavy fuel oil.

SOLID FUELS.

(*a*) **Coal on the grate or on mechanical stokers.**—Can be used efficiently only for fairly continuous service.

Advantages:

(1) Fuel cost is low.
(2) First cost of installation is low.
(3) Total operating cost is low if reliable heaters are employed and proper furnaces are used.
(4) Fuel supply is reliable.
(5) Fuel price is stable.

Disadvantages:

(1) Firebox requires frequent repair, due to high combustion temperatures and action of clinkers.
(2) Firebox and fuel occupy floor space.
(3) Labor of coal and ash handling must be performed.
(4) Competent firemen are needed.
(5) It is difficult to keep competent firemen on account of physical labor.

(6) There is a high furnace loss due to scaling and oxidation, unless design and operation of furnace are most excellent.
(7) Control of furnace temperature is difficult, if rate of heating varies.
(8) Control of furnace atmosphere is difficult.
(9) A stack is needed.
(10) Black smoke is produced if a reducing atmosphere is wanted.
(11) There is sulphur in products of combustion.

(*b*) **Coke on the grate.**—The products of combustion are free from water vapor. Very useful for heating drying chambers. In all other respects, similar to coal on the grate.

(*c*) **Powdered coal.**—Is at present useful in large installations only, because small, individual pulverizers have not yet been developed for powdering coal sufficiently fine for combustion in industrial furnaces.

Advantages:

(1) No labor is necessary to bring fuel to furnace, or to inject it into furnace.
(2) Control of furnace temperature is easy (compared with coal on the grate).
(3) Control of furnace atmosphere is easy (compared with coal on the grate).
(4) Fuel cost is low in large plants.

Disadvantages:

*(1) Flame temperature is high and it is difficult to maintain combustion chamber.
(2) Cost of installing pulverizing plant and coal-feeding mechanism is high.
(3) Fine ash and slag must be disposed of.
(4) It is impossible to use recuperators or regenerators.
(5) There is an explosion hazard in the pulverizing plant.
(6) Heated product may be spoiled by ash deposits.
(7) Abrasive action of floating ash particles damages machinery in shop.
(8) It is difficult to maintain even temperature over a large hearth.

* It will be noted that in some instances high flame temperature has been cited as an advantage, in others as a disadvantage. This, of course, depends on the class of work. For low-temperature work, such as annealing, it is often difficult, with the high-heating-value fuels, to keep the temperature low enough; whereas, in high-temperature work, such as welding, sufficiently high temperatures cannot be obtained with the lean fuels, unless air and fuel are preheated.

(9) Control of furnace atmosphere is difficult (compared to gaseous fuels).

ELECTRICAL ENERGY.

Is rapidly gaining in favor for many heating operations.

Advantages:

(1) There are no products of combustion in furnace or in work-room.
(2) Automatic control of temperature is easy.
(3) Life of furnaces is long, because of absence of combustion chambers.
(4) Installation is simple.
(5) There is no auxiliary equipment of the kind which requires attention.
(6) Operation is simple.
(7) Labor cost is a minimum.
(8) Installation has considerable flexibility, including possibility of moving furnaces about.
(9) Plant may be kept clean without difficulty.
(10) High quality of finished product is possible.
(11) Tendency to scale is small.
(12) Inconvenience to workmen in the plant is a minimum.
(13) Furnace is made ready for use by closing a switch.

Disadvantages:

(1) First cost of furnace and control is high.
(2) Cost of energy per B.t.u. is high.
(3) Furnace heats slowly from cold start.
(4) Heat loss charges are high in case of intermittent operation.
(5) Cost of repairs is high and there is considerable delay in case of burn-out of resistors.
(6) There is a high " service " or " demand " charge by power plant in case of intermittent operation.

A comparison of the cost of various fuels is given in the chart, Fig. 253. This chart holds for simple furnaces of the batch type only; that is to say, it is not applicable to continuous furnaces or to furnaces in which any preheating of the fuel or of the air takes place.

In the comparison of fuels, and of their cost with regard to the cost of the final, perfect, finished product, more than the fuel alone must be taken into consideration. Two examples from practice will illustrate what is meant by this statement. In one plant there existed gas-heated furnaces which were, as a matter

of fact, nothing else but four walls with a roof and a few gas pipes projecting through openings in the walls. The product which was annealed in these furnaces was not evenly heated, and, besides, it showed pitting and scaling which made it unsuitable for nickel plating. These furnaces were replaced by electrically heated furnaces, which, in spite of the much higher cost of heat energy, reduced the cost of the finished product by better heating and by reduced cost of labor. To the owner of the plant the superiority of the electric furnace over the fuel-fired furnace was firmly established. In another plant an electrically heated oven

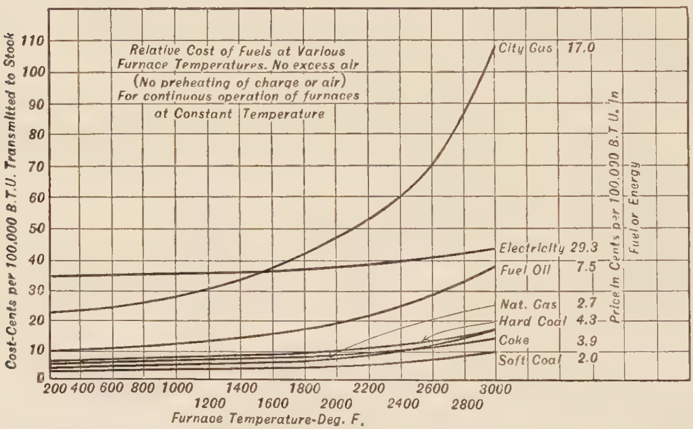

FIG. 253.—Comparison of fuel costs in simple furnaces of the batch type.

was installed, but the oven was not adapted to the use of electrical resistors. In this case the cost of the heat energy per unit of material heated was fully nine times as high as that of oil firing, which was installed later and which gave as good results, with regard to the quality of material heated, as electrical heat. In this case the superiority of fuel firing over electrical heat was just as firmly established as was the superiority of electrical heat over fuel heat in the first case. The apparent contradiction contained in these two cases teaches that each fuel, or source of heat energy, must be considered in conjunction with proper furnace design, burner design, and with proper operation of furnace as well as of fuel-preparation equipment. Any fuel, except those which are full of sulphur or other harmful ingredients, can be

made to do well and to give satisfactory service in a well-designed and skillfully operated furnace.

In comparing fuels or sources of heat energy, however, the human element must be kept in mind. A ready-made, constant source of heat, such as electrical energy, city gas, or natural gas, the flow of which is easily controlled, while in itself not a guarantee of good results, is most certainly a great help in attaining that goal. Very good heat treating, hardening, and other processing has been done with coal or coke on the grate, or with oil, but only by exercising considerable skill and watchfulness. That combination is found in comparatively few men, and those men who meet the specification are seldom willing to work for the wages which a heater is paid. For that reason it frequently pays to disregard B.t.u. costs and to select those sources of heat energy by means of which good results can be obtained with ordinary attention and intelligence.

In the past few years the use of electrical energy for industrial heating has made vast strides. It is therefore appropriate to study its field and its limitations. In a large number of cases electrically heated furnaces have been known to give very much better results than fuel-fired furnaces had given for the same heating process. In many instances, although not in all of them, the fuel-fired furnaces were of an obsolete or home-built, inefficient type. Fuel-fired furnaces are of a character which invites home construction, that is to say, construction by local bricklayers with application of commercial or even home-made combustion devices, in spite of the fact that well-designed fuel-fired furnaces can be purchased on the open market. On the other hand, electrically heated furnaces for many years did not lend themselves to home construction on account of patent protection. Moreover, the calculation of resistors and their application in the furnace were new and little understood. The construction of the temperature-regulating device is so highly specialized that the equipment must be purchased from electrical manufacturers and must be installed by competent furnace men with a knowledge of electrical installation. In consequence, a great deal of engineering talent is built into practically every electrically heated furnace, whereas such engineering talent and specialized knowledge is frequently missing from home-built fuel-fired furnaces. If the purchasers of furnaces would place less reliance upon the ability

of local bricklayers, and would pay more attention and money to reputable furnace engineers and furnace builders, there would be little to choose, in the quality of the heated product, between furnaces heated by electricity and those fired by a clean gas of constant composition. Likewise, there is practically no difference in the labor cost between fuel-fired furnaces and electrically heated furnaces, if a ready-made gaseous fuel is purchased, if proper temperature-regulating devices of automatic character are employed, and if the furnace, as well as the combustion devices, is of proper design and carefully manufactured.

But, aside from the advantages which modern electrically heated furnaces show when compared with obsolete fuel-fired furnaces, the electrical furnace has certain inherent advantages which will secure for it a very large field of application in many manufacturing operations: (1) it can be placed wherever a cable can be run; (2) it radiates a comparatively small amount of heat; and (3) it discharges no products of combustion. On the other hand, it is quite evident that there are many heating processes to which electricity will probably never be applied. As an example we may cite the heating of blooms and billets in a steel plant. An average plant, making 100,000 tons of steel per month, would need a power plant of 50,000-kw. capacity for the heating of the steel, in addition to the 15,000 to 20,000 kw. which are necessary for all other operations.

A great deal of information on different fuels and on combustion devices is contained in Chapters I and II, and these chapters should be referred to before a decision is made on the type of fuel to use in a new installation. In making additions to existing installations the fuel already in use will have its influence upon the new installation.

Additional information on the decision as to what fuel should be used in a given case may be deduced from the amount of equipment which goes along with certain fuels. These remarks do not refer to purchased electrical energy, to natural gas, city gas, coke-oven gas, or blast-furnace gas, because the equipment for making these sources of heat energy lies wholly outside of the plant utilizing them. The remarks refer to raw producer gas, clean producer gas, carbo-gas, water gas, fuel oil, tar, and powdered coal.

Figure 254 gives an idea of the equipment necessary in con-

nection with raw producer gas. The illustration shows an automatic producer, with mechanical feed and mechanical ash removal. Simpler installations can, of course, be made, such as hand-poked

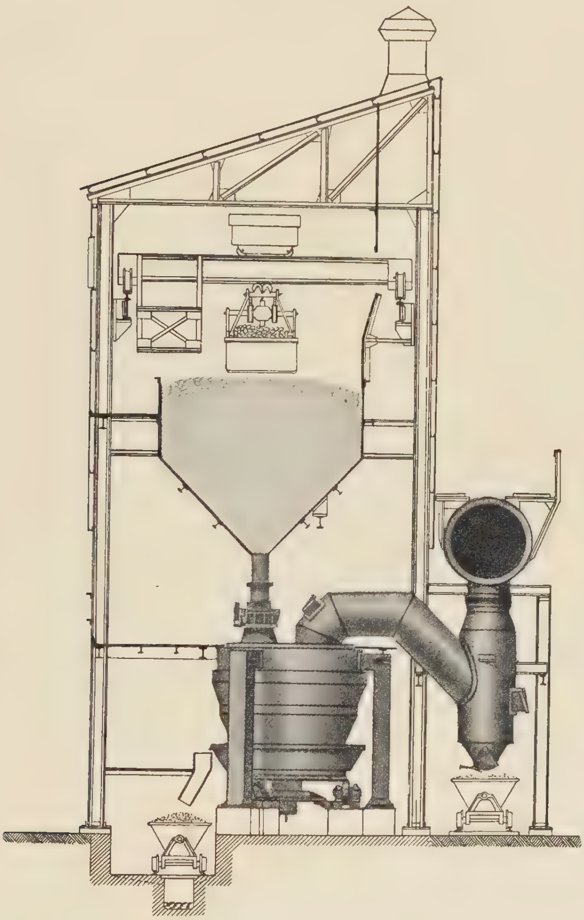

FIG. 254.—Equipment required for making raw producer gas.

producers, with hand charging and ash removal by hand. In such a simple installation the gas is, however, very often of poor quality and, as a rule, of decidedly variable composition, depending upon the attention and zeal of the heater. The interior of the gas house is usually smoky and dirty; and it is difficult to keep

intelligent gas-making men on the job. Figure 254 does not show the steam equipment which is necessary in conjunction with the apparatus for blowing air and steam into the producer. Figure 255 illustrates the equipment which is necessary if clean, cold producer gas is to be applied to industrial furnaces. In addition to the equipment needed in the plant of Fig. 254, the clean pro-

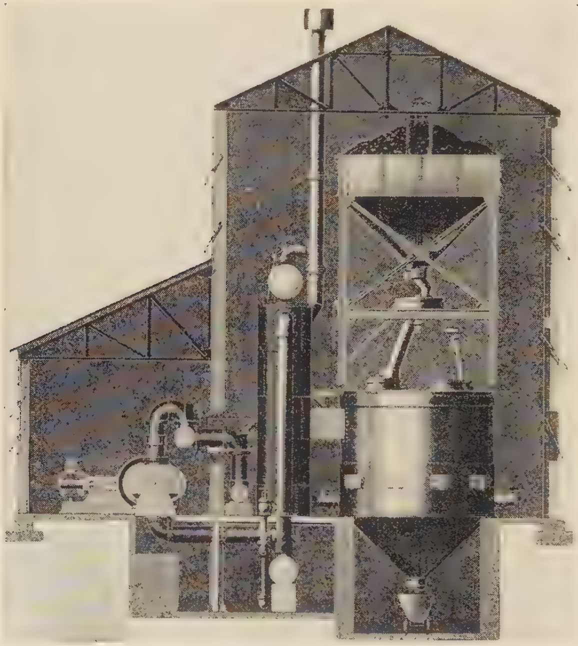

Fig. 255.—Equipment required for making clean producer gas.

ducer gas plant requires a tar extractor, a scrubber, an exhauster driven by a steam engine, and some minor equipment. Figure 255 likewise does not show the steam-boiler equipment which is needed for the operation of the producer plant. The generation of carbo-gas, which, as will be remembered, is a mixture of retort gas and producer gas, requires an equipment which is still more complicated than that represented by Fig. 255. Figure 256 illustrates the equipment which is required for the making of

water gas. This illustration shows the vast amount of small apparatus which, in addition to the large equipment, is necessary for the automatic operation of a blue water gas plant.

Individually as well as collectively, Figs. 254, 255, and 256 drive home the fact that the making of gaseous fuels requires quite an investment, particularly if a clean, cold fuel is to be

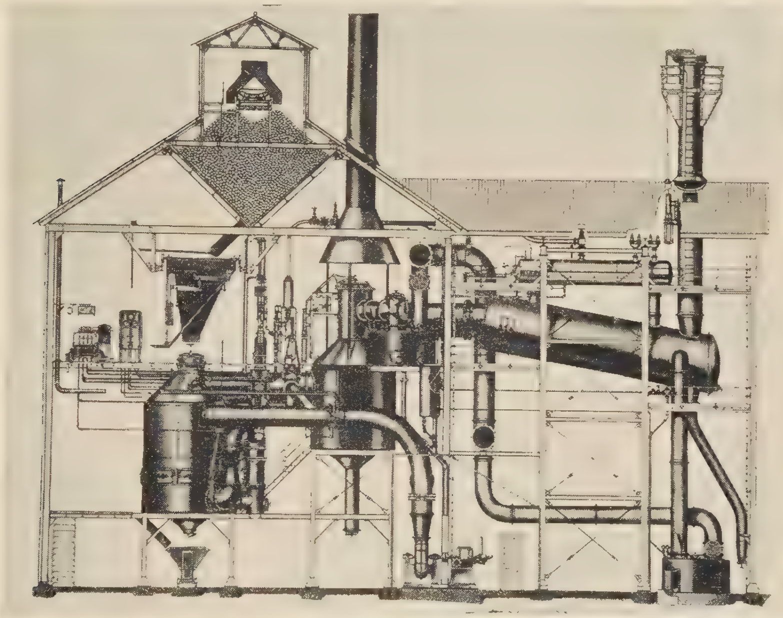

FIG. 256.—Equipment required for making water gas.

distributed to a number of scattered furnaces. If only a few small industrial furnaces are to be operated, the first cost of building the gas plant for serving them is absolutely prohibitive. On the other hand, the installation of gas-making equipment pays for itself whenever a sufficient number of large furnaces, or a great number of small furnaces, are to be served.

Emphasis is again placed on the necessity for great care in gas making and upon fairly steady demand if good results are to be obtained. With widely fluctuating demand, with poor coal, or

with improper attendance at the producers, the best heater and the best-designed furnace will fail to produce good results.

The use of fuel oil also requires the installation of some equipment in addition to the furnace, as can readily be seen by an inspection of Fig. 257, in which are illustrated the fuel storage plant, the oil heater, the oil pump, and the air blower. This equipment has nothing to do with oil refining, but shows what is necessary for oil storage, oil heating, and pumping. It is readily observed, by comparison with Figs. 254, 255, and 256, that the burning of oil does not require nearly as much auxiliary equipment as is required for the making of gas. With very heavy oil additional equipment is required; a steam coil must be inserted into

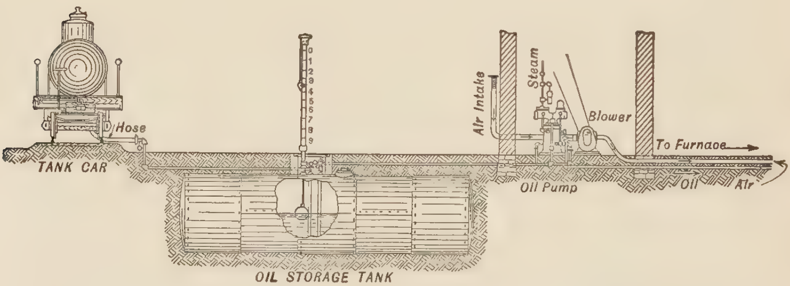

FIG. 257.—Auxiliary equipment for oil-burning furnaces. Additional equipment is needed for heavy, viscous oils.

the tank car, particularly in the winter months. Heating coils must be provided in the storage tank to make the oil fluid enough to flow to the pump. A return pipe must be installed, and the oil must circulate at all times, so that it will be fluid enough for atomization in starting up or with low rates of heating. Arrangements must be made to remove the sludge from the bottom of the storage tank. The same statements hold with regard to tar.

The preparation and the conveying of powdered coal require a considerable amount of equipment. An idea of the extent of this equipment may be had by an examination of Fig. 258, which represents the various steps in making powdered coal, from the receiving of the coal in railroad cars to the sending of the coal

dust through a pipe to the furnace. The illustration, which is otherwise very complete, does not show the hopper which is usually provided at each furnace; neither does it show the combustion devices which were described in Chapter II. It is immediately evident from an inspection of Fig. 258 that a central coal-powdering station is expensive and that it can pay only for large furnaces or for a large number of small furnaces.

It is very probable that powdered coal will be burned in isolated and in small furnaces, just as soon as it is possible to design and build a good individual pulverizing plant which is reasonable in cost and which produces a powder sufficiently fine for furnace use. Figure 259 shows a plant which was described in *London Engineering*, of October 5, 1923. It will be seen that the pulverizer is quite small and inconspicuous in comparison with the size of the furnace. While individual pulverizers are now on the market, they are not wholly satisfactory for industrial furnaces. They produce a reasonably fine powder while new, but the grinding parts wear out rapidly, and coarser and coarser particles are delivered as time goes on. Maintaining a reasonable fineness requires frequent repairs and renewal of parts, the cost of which per ton of coal lies between 4 cents and $7\frac{1}{2}$ cents (in 1924) for boiler work, and would doubtless be much greater for small industrial furnaces, in which sustained fineness is required.

Powdered coal has been successfully applied to the heating of steel for rolling, forging and pressing, and for rough annealing, that is to say, in processes in which the deposits of ash are comparatively harmless. For medium-sized and small work of the above mentioned kind, oil is preferable, unless the nature of the work and labor conditions make gas or electricity necessary.

The range of applicability of coal or coke on the grate was discussed in Chapter II, pages 90 to 104.

These statements indicate the extent to which a general comparison of fuels and sources of energy for industrial furnaces can be carried. It is quite obvious that, in each individual and specific case, additional information must be considered, and examples of such considerations are given in Chapter VII, under "Selection of Fuels and Furnaces to Suit Plant Conditions."

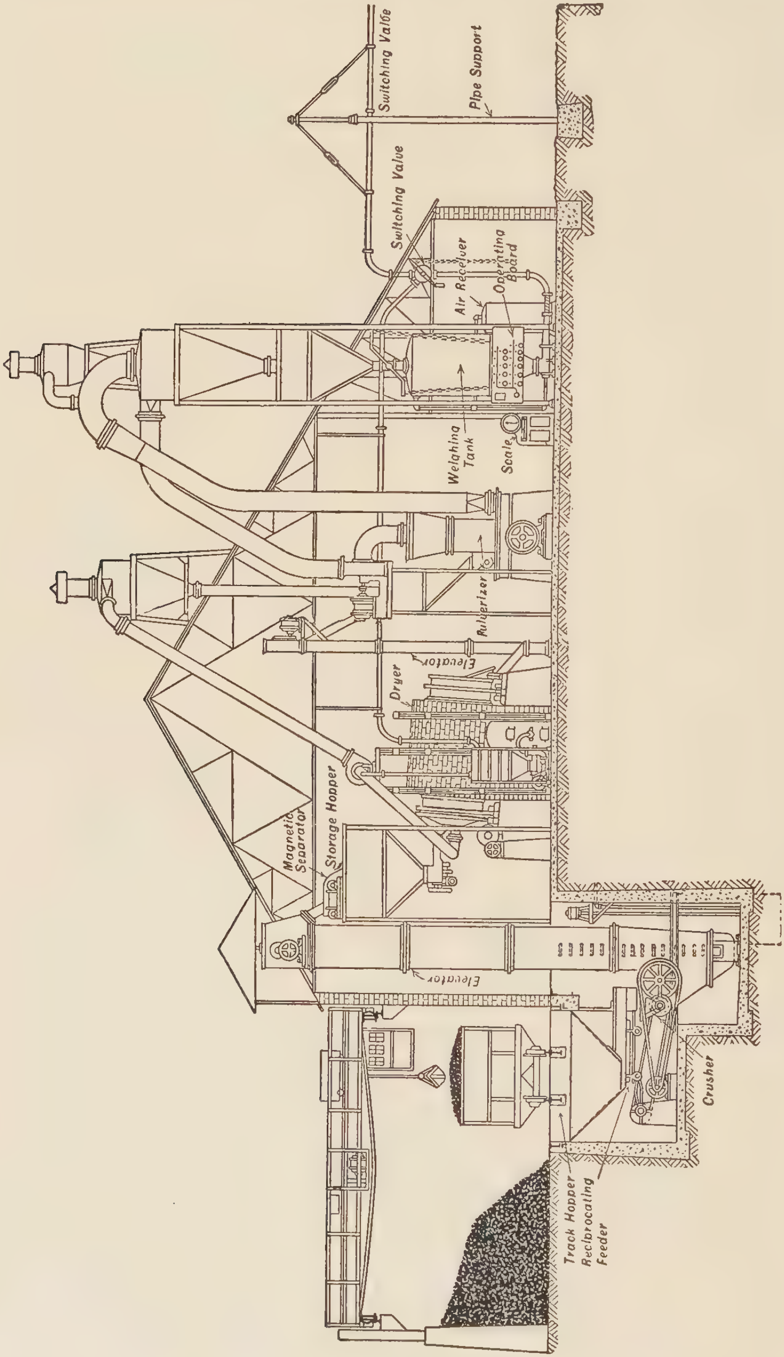

FIG. 258.—Central coal-pulverizing plant.

Note the variety of equipment which must be maintained.

Utilization of Waste Heat.—In the selection of furnaces it is almost invariably necessary to decide whether the furnace shall be of the simplest possible type, without any utilization of waste heat, or whether it shall be of a more complicated type, in which waste heat is utilized. To a large extent this question was discussed in Volume I. It remains to review briefly the statements made there and to supplement them by a summary of the advantages and disadvantages of the different methods of heat utilization.

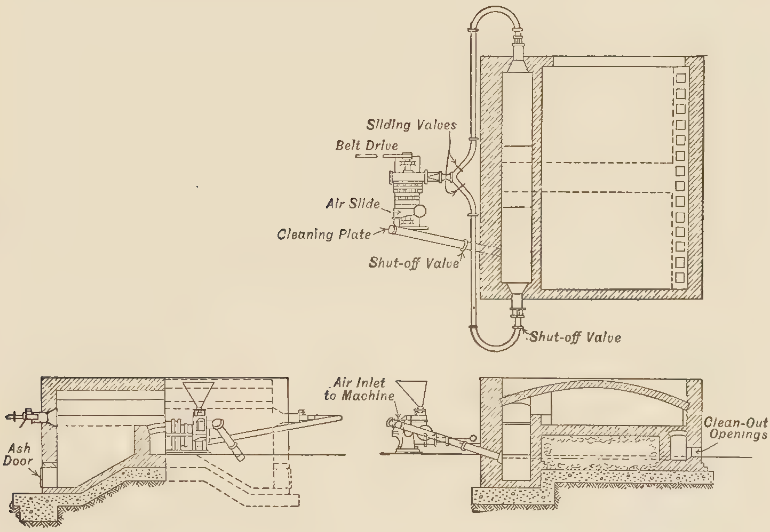

FIG. 259.—Plate-heating furnace equipped with individual pulverizer.

The advisability of spending money for heat utilization depends almost entirely upon the possibility of getting back the investment by savings in operation. In connection with furnaces which are used very intermittently, heat salvage does not pay, because the saving effected by reduced fuel consumption is very small in comparison with the investment which must be made to effect that saving. If, on the other hand, the furnace is used rather continuously, and particularly if temperatures in excess of 1600° F. are used in it, the cost of equipment for heat salvage pays good dividends. A moderate amount of preheating of the stock pays for itself in almost all cases, even in intermittently

used furnaces, such as furnaces for hardening high-speed steel, in which a preheating chamber is arranged above the regular heating chamber at very little additional cost. It pays in all continuous furnaces, as is evident by a study of the curves (Figs. 92, 93, and 96) in Volume I. From these curves it is clear that the utilization of fuel in continuous furnaces is quite good, if the rate of heating is so low that the products of combustion leave at a temperature below 1400° F. In the heating of steel this corresponds to a rate of 35 to 55 pounds of steel per square foot of hearth and hour; the fuel consumption rises rapidly as the rate of driving the furnace is increased. If continuous furnaces are driven at the above rate of heating, namely, somewhere between 40 and 55 pounds of steel per square foot of hearth per hour, additional heat-saving devices, such as regenerators or recuperators, or even waste-heat boilers, pay only a small interest on the investment, because the heat in the products of combustion is very well utilized by the preheating of the heating stock. In forging plants preheating of ingots or of very large billets is practiced, for reasons which have nothing to do with fuel economy, but which relate solely to the prevention of cracking of the ingots.

If material is to be annealed only, its temperature is raised above a certain critical value, and it is then brought down again to room temperature. If the cooling takes place in the open atmosphere, the heat which was imparted to the material is lost. By an ingenious arrangement and the expenditure of some money it is possible to salvage a large part of the heat, if slow cooling of the stock is permissible. If, for instance, two parallel trains of the material (which is to be annealed) are arranged to move through a long furnace in opposite directions, as indicated in Fig. 260, the heat given off by the outgoing material is to a large extent absorbed by the ingoing material. In practice, complete heat exchange, which is known as " regeneration " or " compensation " would require a very long and expensive furnace and an absolutely heat-tight structure. For both of these reasons the furnace is made shorter than it would have to be for complete heat interchange, and the amount of heat added in the central chamber depends upon the furnace construction. The principle of heat interchange, or regeneration, is practiced extensively in electrically heated furnaces (more so than in fuel-fired furnaces), on account of the high cost of electrical energy. In locations

with cheap electrical energy annealing furnaces are shortened still more and are built for very incomplete heat recovery, as

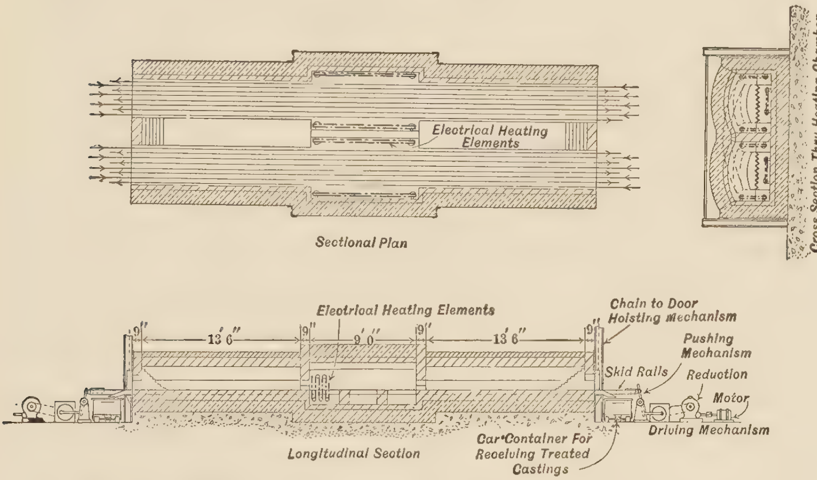

FIG. 260.—Electrically heated annealing furnace of the regenerative or compensating type.

shown in Fig. 261. In this furnace less than one-half of the heat of the charge can be salvaged by recuperation. It may be re-

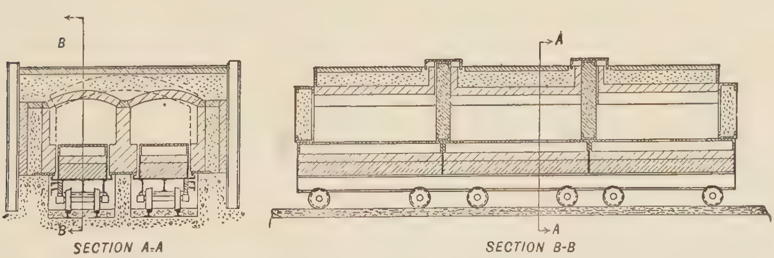

FIG. 261.—Abbreviated annealing furnace of the compensating type. On account of the short length, heat salvage is very incomplete.

marked again that regeneration is impossible if the stock must be cooled quickly, as in quenching or normalizing.

In addition to heat salvage by preheating of stock three other

methods are possible in fuel-fired furnaces, namely, heat salvage by (1) waste-heat boilers, (2) regeneration of air, and (3) recuperation. Waste-heat boilers and their field of applicability were discussed so extensively in Volume I that very little remains to be added here. In large forge plants, where the use of waste-heat boilers

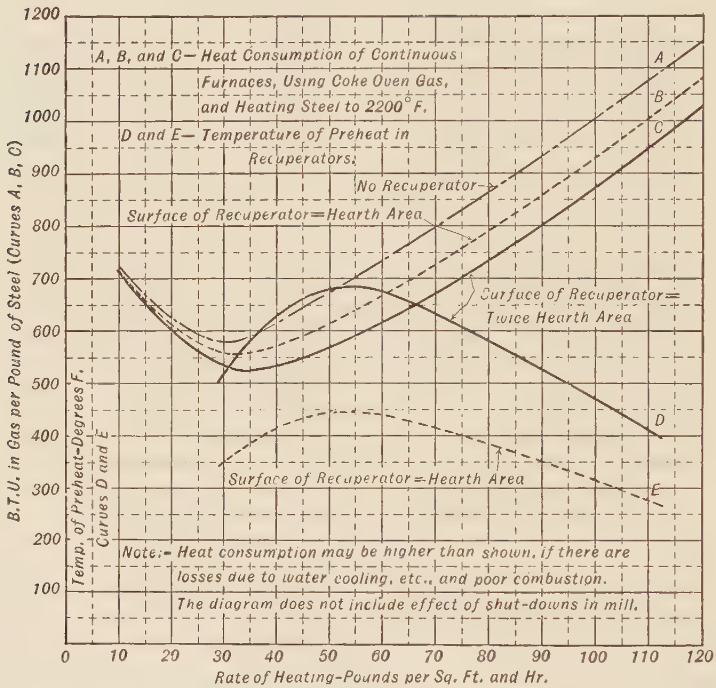

FIG. 262.—Heat consumption, and temperature of preheat, of continuous furnaces with recuperators of different sizes, at various rates of heating. The fuel is coke-oven gas. The improvements of furnace operation (less scaling, heat salvage due to late combustion of excess fuel) are not taken care of in the diagram.

might, offhand, appear to be extremely desirable, it has been found economical, particularly in districts of comparatively cheap fuel, to waste the heat contained in the products of combustion and to produce steam for the hammers and presses in a centrally located economical boiler plant. The maintenance and operation of many scattered, inaccessibly located boilers was found to require so much labor and supervision that its cost outweighed

the cost of additional fuel many times over. From the standpoint of conservation of natural resources this fact is deplorable, but from the standpoint of dollars and cents to the owner of the forge plants it was the only right step to take.

The problem of whether furnaces shall be equipped with regenerators or with recuperators, or whether any heat salvage shall be attempted at all, is one which invariably presents itself in the installation of fuel-heated furnace equipment. In one of the preceding sections the statement was made that the fuel economy of continuous furnaces that are driven at moderate rates cannot be sufficiently improved by the addition of regenerators or recuperators to warrant their installation. The case is different with simple furnaces using no preheating of the stock and with continuous furnaces that are driven very hard. In the heating of steel hard driving corresponds to a rate of 70 to 120 pounds of steel per square foot and hour.

The heat consumption of a continuous furnace, when heating steel to 2200° F. and when working with or without recuperation, was plotted in Fig. 262, as a function of the rate of heating. The calculations were based upon the assumptions made on pages 122 and 123 of Volume I. A study of the curves teaches that a hard-driven furnace with a large recuperator can be made as economical as a more lightly loaded furnace without a recuperator.

With furnaces of the batch type, and with hard-driven continuous furnaces, recuperators pay, provided they are properly designed, properly built, and properly operated, and provided the use of the furnaces is not too intermittent. The correctness of this statement is proved by the calculation of two examples, one for a batch-type furnace, and the other for a continuous furnace.

As a first example, take the furnace which was analyzed on pages 102 to 107 of Volume I. Let the furnace be under fire 70 per cent of the total days in a year, with 9 hours operation per day. This fraction allows for repairs, dull periods in business, Sundays, and holidays. The furnace is actually in operation a little more than 26 per cent of the total number of hours in a year. Then the fuel consumption per year is:

$$\underset{\substack{\text{(Heating value,}\\ \text{B.t.u. per pound)}}}{\overset{\text{(B.t.u. in fuel/day)}}{\frac{14{,}885{,}000}{19{,}980}}} \times \underset{\substack{\text{(pounds per}\\ \text{gallon)}}}{\overset{\text{(Days/year)}}{\frac{0.70\times 365}{6.8}}} = 28{,}000 \text{ gallons per year.}$$

At 6 cents per gallon, the fuel would cost \$1680. If the air is preheated to 1000° F., the saving is approximately 28 per cent (see page 137, Volume I) or \$504. The ideal recuperator surface for a furnace requiring one million B.t.u. per hour useful heat plus radiation and convection losses (see page 149, Volume I) is about 70 sq. ft. The furnace in question requires:

$$\frac{(2{,}880{,}000+1{,}896{,}000+1{,}133{,}000+59{,}000+847{,}000) \text{ B.t.u. per day}}{9 \text{ hours per day}} = 757{,}000 \text{ B.t.u. per hour.}$$

Hence the recuperator surface is

$$\frac{70\times 0.757}{0.7}=76 \text{ sq. ft.}$$

The factor 0.7 takes care of contingencies, as noted in Volume I, page 150.

For the purpose of this example, assume that the recuperator is built of an iron-chromium alloy which can be rolled into sheets and can be welded; let the sheets be $\frac{1}{16}$ in. thick; then the weight of 76 sq. ft. equals $\frac{76\times 144}{16}$ cu. in. $\times 0.283=194$ lb.; add 35 per cent for completing the recuperator box; then total weight of box $=1.35\times 194=262$ lb. Let the material cost 70 cents per pound; then the cost of material of the recuperator = \$184. Let the making cost \$200, and let a recuperator last 3 years; then the yearly cost of recuperator, including taxes and interest, will be about \$140. The recuperator will reduce the scaling of the material at least $\frac{1}{4}$ per cent of the material heated or

$$\frac{1040 \text{ lb./hour}\times 8 \text{ hours}}{400}\times 0.7\times 365=5310 \text{ lb. per year.}$$

At \$40 per net ton, the saving equals \$106. In addition to this saving and the direct saving in heat calculated above, there is also a saving due to better combustion, so that the total yearly saving may be put at \$650 with a yearly cost of \$130 to \$150.

The correctness of this calculation is based upon the assumption that the recuperator will last three years. It is only within the last few years that metallic materials have been available which make this assumption a reality.

A similar calculation can be carried out for continuous furnaces. A hard-driven furnace of 100 square feet hearth surface offers a good example. A calculation will be made for a top-fired furnace, using producer gas, and heating at the rate of 100 pounds per square foot per hour.

From Figs. 90 and 92, Volume I, the temperature of the gases leaving the furnace = 2200° F., and the minimum fuel consumption = 8.4 cu. ft. of producer gas per pound of steel. From Figs. 93 and 99, Volume I, it is seen that

allowance must be made for added losses. A reasonable amount would be 33 per cent.

133 per cent $\times 8.4 = 11.2$ cu. ft. of gas per pound of steel.

100 lb. per square foot per hour $\times 100$ sq. ft. $= 10{,}000$ lb. of steel heated per hour.

$$\frac{11.2 \times 10{,}000}{3600} = 31.1 \text{ cu. ft. of gas per second without recuperator.}$$

Let the air be preheated to 800° F. From Fig. 69, Volume I, the combustion heat is 138.7 B.t.u. per cubic foot of gas, the heat in the gases leaving is 100 B.t.u., and the heat utilized in the furnace is $138.7 - 100 = 38.7$ B.t.u. per cubic foot. If the combustion air is preheated to 800° F., the heat in the air is 15 B.t.u., and the heat utilized is $138.7 + 15 - 100 = 53.7$ B.t.u. per cubic foot. The fuel consumption with recuperation is 72 per cent of that without recuperation, or the saving is 28 per cent of the fuel.[1]

The air required is 0.09 lb. per cubic foot of gas (Fig. 69, Volume I) or

$0.09 \times 31.1 \times 3600 \times 0.72 = 7260$ lb. of air per hour.

There is 0.162 lb. of waste gases, including 5 per cent excess air entering the furnace, for 0.09 lb. theoretical air. The drop in temperature of the gases in the recuperator is approximately $\frac{0.09}{0.162} = 55.6$ per cent of the temperature rise of the air.

This is not exact, because the gases have a somewhat higher specific heat than the air; but the error is slight.

Referring to Fig. 111, Volume I, and taking $K = 2.5$, we obtain from equation (6), page 141, Volume I:

$$2.5 \times A \times \left[\underset{\substack{\text{(Average gas}\\ \text{temperature)}}}{\frac{2200 + t_{2g}}{2}} - \underset{\substack{\text{(Average air}\\ \text{temperature)}}}{\frac{t_{1a} + 100}{2}} \right] = 7260 \times 0.25 \times (t_{1a} - 100) \quad . \quad (12)$$

Also,

$$\underset{\substack{\text{(Temperature}\\ \text{drop of gas)}}}{(2200 - t_{2g})} = 0.556 \times \underset{\substack{\text{(Temperature}\\ \text{rise of air)}}}{(t_{1a} - 100)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

Since $t_{1a} = 800$, equation (13) gives $t_{2g} = 1811$. Substitution in equation (12) gives $A = 327$ sq. ft. of recuperator surface required. To take care of adverse conditions, 25 per cent will be added.

Cost of recuperator material:

$$327 \text{ sq. ft.} \times 1.25 \times 144 \times \tfrac{1}{16} \text{ in.} \times 0.283 \text{ lb./cu. in.} \times \$0.70\text{/lb.} = \$730.$$

Allowing 110 per cent for cost of casing and fabrication,

210 per cent of \$730 = approximately \$1530.

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[1] Actually, the temperature distribution in the furnace changes, and, since the weight of products of combustion is less, they leave at a lower temperature. The calculation is therefore not absolutely accurate, but the error is negligibly small.

If the recuperator lasts 3 years, replacement cost $= \frac{1}{3} \times \$1530 = \$510$; allowing for interest, taxes, and other costs, about \$700 per year.

Saving in cost of fuel:

$$\frac{28 \text{ per cent} \times 31.1 \text{ cu. ft./sec.} \times 3600 \times 20 \text{ hr./day} \times 250 \text{ days/yr.} \times \$3/\text{ton}}{65 \text{ cu. ft. gas/lb. coal} \times 2000 \text{ lb. per ton}} = \$3620 \text{ per year.}$$

Saving by reduction in scaling, with billets at \$40 per ton, is

$$\frac{\frac{1}{4} \text{ per cent} \times \$40 \times 10{,}000 \text{ lb./hr.} \times 20 \text{ hr./day} \times 250 \text{ days/yr.}}{2240 \text{ lb./ton}} = \$2230 \text{ per year.}$$

This is a minimum saving; in most cases the reduction in scaling is much greater than the assumed value.

$$\text{Net saving} = 3620 + 2230 - 700 = \$5150 \text{ per year.}$$

This represents a return of 337 per cent on the investment.

If the cost of fabrication were even twice as great as figured above, the cost of recuperator would be

$$\begin{aligned} &320 \text{ per cent} \times \$730 &&= \$2335 \\ &\text{Replacement cost, etc., per year} &&= \$1090 \\ &\text{Net saving} = 3620 + 2230 - 1090 &&= \$4760, \end{aligned}$$

representing a return of 205 per cent, which is still a sufficiently wide margin.

These calculations prove that properly designed and properly installed recuperators pay good dividends. While the calculations were made for metallic recuperators, the conclusions hold just as well for properly designed tile recuperators.

If recuperators have not been extensively used in the past it has not been for want of similar economic calculations, but rather because the materials were not available to build recuperators which would last under adverse conditions and would not burn out or crack rapidly if operated without great care. Moreover, recuperators were usually located in inaccessible places.

There have also been difficulties in the control of furnace atmosphere, because the density of the combustion air varies with the temperature of preheat. Additional difficulties arise from the fact that many furnaces discharge the products of combustion through widely scattered flues, and that the collecting of these products into a single recuperator presents some difficulties. However, these difficulties are not insurmountable. Furthermore, separate recuperators utilizing the heat in the gases coming from each flue or group of flues can be arranged.

These constructional difficulties are rapidly being overcome, and it is probable that recuperators will in the future be used more extensively on oil-fired furnaces and on gas-fired furnaces. With coal on the grate and with powdered coal, only very moderate temperatures of preheat can be utilized.

It may not be amiss to mention, for purposes of comparison, a few types of recuperators in addition to those described in Volume I. Figure 263 shows an interesting design which was evolved on the European Continent. Rectangular tiles are laid diagonally on 45-degree blocks. Air and flue-gas circulation are at right angles to each other. The bottom tiles do not support the weight of all the tiles lying immediately above them, but the weight of the upper layers is carried on the projecting ledges on the sides of the recuperator. This method of support very much reduces the danger of cracking, which was mentioned in Volume I as one of the greatest enemies of tile recuperators. Furthermore, recuperators of this type are, of late, made of a silicon carbide mixture, which is mechanically very much stronger than firebrick and has a much greater heat conductivity. Both properties reduce the danger of cracking very considerably and broaden the field of usefulness of the tile recuperator.

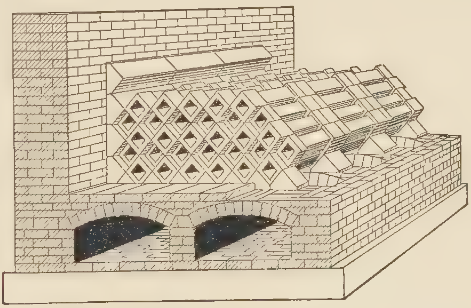

FIG. 263.—Tile recuperator with rectangular blocks laid at 45 degrees.

Figure 264 represents a chimney type of recuperator which is made of metal.[1] This type of heat-salvaging equipment has the advantage that it can be placed on top of almost any furnace and can serve as an "after thought." In former years metallic recuper-

[1] The recuperator illustrated in Fig. 264 is not durable in the form there shown, because the fire tubes assume sufficiently different temperatures to produce loosening of the tubes in the end sheets. The design has been improved in a logical manner, and recuperators of the new type are in successful operation. On account of the patent situation, drawings of the new design had not yet been released at the time this book went to press.

ators were limited to low-temperature work, because no materials were available which would successfully resist the high temperature of products of combustion. Lately, manufacturers have learned to coat steel with protecting materials and to make heat-resisting alloys which are sold under various trade names. If no flame impinges directly upon the walls of the recuperator, steel walls coated with aluminum oxide withstand a temperature of the

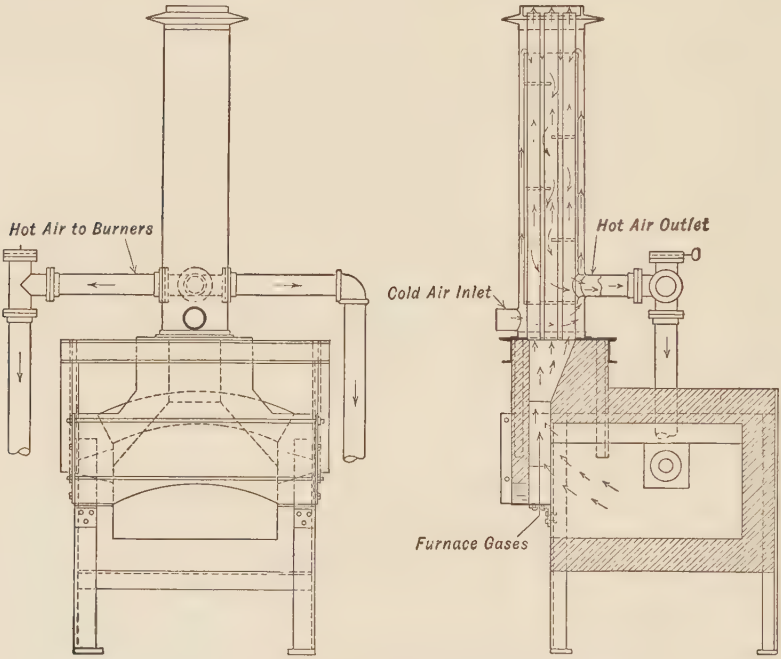

FIG. 264.—Stack type of recuperator as applied to forging furnace.

products of combustion of about 1800° F. Accurate data on the length of life of such recuperators are not available, because of the different conditions to which they are subjected. With a furnace temperature of 1800° or less, and with proper direction of the products of combustion, steel coated with aluminum oxide furnishes a durable, although somewhat expensive, recuperator material. For rolling and forging temperatures the alloys of about 70 per cent iron and 30 per cent chromium doubtless form a much safer material, because these alloys will continuously

withstand temperatures up to 2000° F. without oxidation and without softening. An additional advantage of these iron-chromium alloys is that they can be rolled into sheets, and that the sheets can be welded into boxes, tubes, or other simple shapes. Under certain conditions the iron-chromium alloys become extremely brittle. This fact must be taken into account in the design of recuperators.

Stimulated by the existence of these new materials, furnace builders and furnace owners are, at the present time, evolving new forms of recuperators, paying due attention to expansion by heat. At the time of publication of this book a large number of these recuperators will doubtless be in the patent office and a few will have been adopted in practice.

Recuperators have come into disrepute because they were frequently located in out-of-the-way and inaccessible places. For instance, they were often placed directly below the furnace, and no means of reaching them or replacing worn-out and burned-out parts was provided. In the United States there are in operation hundreds of furnaces below which are collapsed, burned-out, or cracked recuperators which have been by-passed and which are sad examples of wrong engineering. Recuperators must be so arranged that they can be regularly inspected without trouble and that, in case of any burning out or cracking, the damaged sections can be replaced with a minimum amount of labor and inconvenience. If the recuperator in a furnace must consist of different sections it is imperative that all sections be alike, so that one spare will do for all of them. For further information on recuperators reference may be had to Volume I.

In fuel-fired furnaces for annealing material which can be cooled slowly the above-mentioned principle of regeneration or compensation (heat exchange between outgoing and incoming material) has been coupled with recuperation, and very economical furnaces have been produced. They are known as channel furnaces or tunnel kilns. A furnace of that type is illustrated on page 10 of Volume I. The tunnel kiln is expensive; its use is indicated for steady mass production, that is to say, for continuous annealing of similar shapes.

Regenerative furnaces have a very limited field in industrial heating. Much floor space is required, in addition to the furnace proper, by the reversing valves and the stack. The regenerators,

which must necessarily be below the furnace, must be made accessible for inspection and repair. This requirement means a deep and spacious excavation. There are practically no small regenerative furnaces in use, because a regenerative furnace is not portable and because regular reversing requires attention. This type of furnace cannot be moved with any ease; it needs a tall stack; and it becomes part of the building. Instead of its fitting into the natural course of manufacturing operations, the course of manufacturing operations must frequently be changed to suit the furnace. Its use is limited to-day to the heating of large forgings, forging ingots and other irregular pieces of varying size which cannot well be pushed through a continuous furnace. For much of this work, recuperators will eventually be used, except where the recuperator would become clogged up, because of the nature of the products of combustion.

Most regenerative furnaces, especially those located in steel plants, are equipped for burning producer gas. This fuel can be preheated in a regenerator without any trouble, but would cause difficulty in a recuperator on account of carbon deposits. In a regenerator the carbon deposits are burned out at practically every reversal, whereas they would accumulate in a recuperator and clog it in a comparatively short time. In forge furnaces for heating high-carbon steel the economy secured by heat salvage in regenerators is to a large extent imaginary, because the whole furnace, including the regenerators, must be cooled down after each heat for the purpose of avoiding injuries to the cold ingot which is to form the next heat. In that case a very much simpler type of furnace will do just as well, or better. If heat economy is to be secured by the regenerative system the steel must be preheated beyond the range of blue-brittleness in a separate preheating furnace. With soft steel, such as structural steel, preheating is not necessary, and the steel can be put into the hot furnaces. If a regenerative furnace is to be made automatic with regard to temperature control or atmosphere control a great deal of equipment is necessary.

Method of Heat Transfer.—Furnaces can be compared with regard to the method of transfer of heat from the source of heat to the charge, and by this method of classification can be divided into three groups. In one of them the heat is transferred from the heating medium, whether it be products of combustion or

electrical resistors, directly to the charge, no wall intervening. This type is frequently called the direct-fired type, or the open-chamber type, or the oven type, or the unmuffled type. In the second class of furnaces heat is transferred to the charge through a muffle, that is to say, through a separating wall, and the inside of the muffle is filled with a gaseous medium, such as air or steam. This group of furnaces is commonly called the "muffle type." In the third type there is also a separating wall between the source of heat and the material to be heated, but the latter is immersed in a liquid. To this type belong lead-pot furnaces and salt-bath furnaces.

The three types will now be compared for the purpose of determining the range of applicability and usefulness of each.

The open-chamber or oven type is by far the simplest of the three and is used wherever it produces sufficiently good heating. In fuel-fired furnaces the presence of the products of combustion in the heating chamber, and the effect which these products of combustion have upon the quality and the surface of the material being heated, is frequently a disadvantage of the oven type. In electrically heated furnaces the open-chamber type is very common, although it has a certain disadvantage. There is an ever-present possibility of short-circuiting and burning out the resistors by the charge, either by having the charge come in contact with the resistors or else by having small pieces of scale, enamel, or other material drop off and short-circuit the resistors. Repairs to electrically heated furnaces are notoriously slow, and burning out of the ribbon-type resistors usually means a shut-down of several weeks. In some of the latest designs of electrically heated furnaces these troubles have been recognized and, to a certain extent, avoided. Under the heading of "Resistors," in Chapter II, on pages 140–144, the various designs which have been brought out for that purpose were discussed. With these modern designs of more or less protected resistors the unmuffled furnace will doubtless be used very extensively for temperatures approaching the danger line with regard to the life of the resistors. The reasoning is that it is better to take a chance of having a resistor burned out by occasional contact with the charge than it is to face the certainty of having it burned out at regular intervals by overheating. For temperatures around 1400° F., or for lower temperatures, the protection of the heating elements by

muffles offers so many advantages that the muffle type or semi-muffle type will probably survive the longest. By the semi-muffle type is meant a design such as that shown in Fig. 265, in which muffle plates are arranged between the charge and the heating elements but these muffle plates are perforated by a large number of comparatively small holes, the small diameter of which considerably reduces the chances of having any foreign material come in contact with the heating elements.

Whenever the muffle is used it should be used with the understanding that it is the lesser of two evils; the advantages of an unmuffled, or practically unmuffled, electric furnace are well known. The absence of a muffle or the use of a thin, perforated

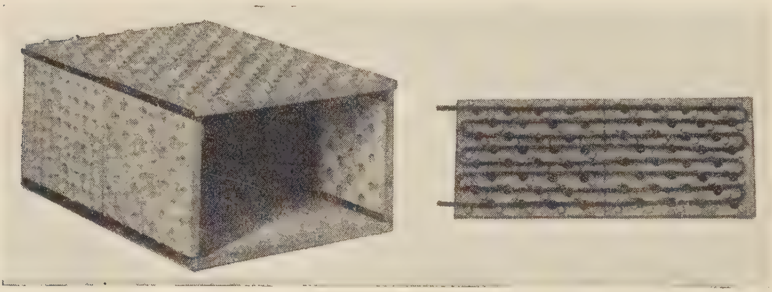

FIG. 265.—Perforated muffle, used in "semi-muffle" type of electrically heated furnace.

muffle allows the resistor, or heating element, to work at a lower temperature than it has to carry when a muffle is used. The unmuffled open chamber also makes the temperature control act more quickly, and a little more correctly, than it does with the muffle. There is not so much overshooting of the mark in temperature regulation as there necessarily must be when a muffle is used. However, these facts have often been exaggerated for commercial reasons.

As above stated, the muffle is not used with fuel-fired furnaces, except when the products of combustion have a deleterious influence upon the material being heated. The reasons for avoiding the muffle whenever possible are very plain and were, to a large extent, discussed in Volume I. Muffles burn out or crack, and besides, cause a great increase in fuel consumption compared to the direct-heating, or oven, type of furnace. This condition has

lately been modified to a certain extent by the use of muffles of silicon carbide or of alloys of iron and chromium; but although muffles of these materials have a high heat conductivity and comparatively great mechanical strength they do not entirely eliminate the heat losses which any muffle involves. Besides, all muffles have one drawback, and that is the lack of circulation of the gases inside the muffle. This feature is shared alike by fuel-fired muffles and by electrically heated furnaces. The only circulation which is set up comes from uneven temperatures inside the muffle or the electrically heated furnace. The charge in a fuel-fired muffle furnace is, therefore, heated only by that "hot and penetrating radiant heat" which is praised so much in advertisements of electrically heated furnaces. Such advertisements try to make a virtue of necessity.

In fuel-fired furnaces the muffle type must, with many fuels, be used for ceramic wares, for the annealing of brass goods, for heat-treating operations where a comparatively clean surface, free from scale, is demanded, and in all bright annealing work, such as was described under "Control of Furnace Atmosphere" in Chapter IV. Sheets are commonly annealed in annealing boxes, which are virtually muffles, and in continuous sheet-annealing furnaces, channel furnaces, or tunnel furnaces (all of which mean the same furnace); in the tunnel kiln, silicon carbide is successfully applied for preheating the products of combustion in the most economical manner. Summing up, we may say that muffles are used only where their extra first cost and the increased cost of operation are warranted by a better quality of heated product. In many cases a higher-grade fuel and a better type of combustion device will give fully as good results in an open furnace as would be obtained in a muffle furnace employing a lower grade of fuel.

Salt Baths and Lead Baths.—Whenever heating with perfect freedom from scaling, carburization, or decarburization is to be attained, as in the hardening and tempering of fine tools, salt baths or lead baths are resorted to; as previously stated, they are a modification of the muffle furnace. The material to be heated is submerged in a bath during a certain time, until there has been sufficient opportunity for thorough heat transmission and temperature equalization, and is then either quenched or given other subsequent treatment. Salt baths and lead baths are almost

entirely limited to tool work in their application. Cyanide baths are used for hardening other shapes besides tools.

Lead baths are extensively used, but they are limited to comparatively low temperatures, because lead begins to vaporize around 1200° F., and volatilizes more and more rapidly as it is heated higher and higher above that point. The vapors are poisonous; for that reason lead furnaces should be equipped with hoods for carrying away the poisonous fumes. Lead baths are well adapted for heating small pieces which must be hardened in quantities. The pieces are put into a basket, which is submerged in the lead. Lead baths do not affect the quenching oil. For temperatures above 1470° F. lead baths are not satisfactory, and salt baths are substituted.

A very large number of salts and salt baths are in use for heat-treating tools. A very good list of salts and mixtures was given by Sam Tour in the August, 1924, number of the *Transactions of the American Society for Steel Treating.* The tables are herewith reproduced:

TABLE XXIV

SALT MIXTURES

Composition	Melting Point, °F.	Usable Range, °F.	Remarks
55% $NaNO_3$ +45% $NaNO_2$	430	430– 900	
55% KNO_3 +45% $NaNO_3$	425	425– 900	
28% NaCl +72% $CaCl_2$	940	1000–1600	Decarburizes above 1500°
50% Na_2CO_3+50% KCl	1040	1100–1500	Breaks down above 1500°
50% NaCl +50% K_2CO_3	1040	1100–1500	Breaks down above 1500°
35% NaCl +65% Na_2CO_3	1150	1200–1500	Breaks down above 1500°
50% $CaCl_2$ +50% $BaCl_2$	1112	1200–1650	Decarburizes above 1500°
22% NaCl +78% $BaCl_2$	1175	1250–1650	Decarburizes above 1500°
44% NaCl +56% KCl	1228	1300–1600	Decarburizes above 1500°

The salts mentioned in these tables are intended only to transmit heat to the material immersed in them, and not to have any chemical action. Unfortunately, the salts do not "stay put," but change with time, causing pitting and corrosion of the material to be heated.

TABLE XXV

SALTS

Name	Formula	Melting Point, °F.
Sodium nitrite	$NaNO_2$	543
Sodium nitrate	$NaNO_3$	590
Potassium nitrate	KNO_3	642
Potassium cyanide	KCN	1035
Sodium cyanide	NaCN	1040
Calcium chloride	$CaCl_2$	1422
Potassium chloride	KCl	1454
Sodium chloride	NaCl	1488
Sodium carbonate	Na_2CO_3	1560
Potassium carbonate	K_2CO_3	1670
Barium chloride	$BaCl_2$	1760

In the case of cyanide salt baths an exception must be made to the statement made above regarding chemical action, inasmuch as a chemical action is desired when these baths are employed. They are used for the purpose of producing a thin skin of hard material on soft steel. The temperature at which the cyanide bath is operated depends upon the kind of steel being treated and upon the desired thickness of the hard skin. The latter is commonly called the case. Sodium cyanide or mixtures of sodium cyanide, sodium chloride, and sodium carbonate are usually employed for hardening. Sodium cyanide itself is decomposed by high temperatures, with the formation of sodium carbonate and the liberation of cyanogen. In consequence, the cyanide content of the bath decreases while the carbonate content increases. There is apparently no advantage in having the cyanide content over 25 per cent. To maintain the proper cyanide content it is necessary to add material to the bath from time to time, not only for the reason stated above, but also because some mixture is lost by being carried out with the work. As the temperature of a cyanide bath is raised, the carbonizing effect rapidly increases. With low temperatures the skin may be raised only a few points in carbon, whereas, with temperatures of 1500° F. a very high carbon content will be obtained.

Cyanide vapors are extremely poisonous; hoods must be provided for carrying away the fumes, as described in Chapter V, page 295. For further details on salt baths the above-cited paper and others contained in the *Transactions of the American Society for Steel Treating* may be consulted.

Liquid heating baths are used for no other reason except that of having the material come out with an absolutely clean surface. The advantage so often claimed for liquid baths, that they heat the material more uniformly and more gradually than the oven type of furnace, cannot be maintained. Heat transfer from a molten liquid to an immersed solid is certainly just as quick as (if not quicker than) it is from surrounding furnace walls having the same temperature as that of the molten liquid. On the other hand, the tools to be heated are usually suspended in the bath of molten liquid, and are, for that reason, exposed to heating from all sides. If they were suspended in a similar way in an oven type of furnace, heat transmission to them would be just as uniform as it is in salt or lead baths. Pieces with sharp corners, or with both thin and thick sections, should not be put into liquid baths without preheating. Steel does not scale below 900° F., and scales very slowly between 900° and 1100° F. It is advisable to heat delicate and expensive pieces to 900° or 1000° F. in an oven type of furnace, the temperature of which is kept somewhere around 1100° F. before they are dipped into the liquid bath, which has a higher temperature.

The advantages of salt baths and of lead baths are not to be had without some disadvantages. Salt retained on the steel has a tendency to change the composition of the quenching bath. The containers of lead or of salt are frequently exposed to a very oxidizing atmosphere on the outside, and burn out or crack, discharging their contents into the bottom of the furnace. Temperature differences in heating up, and strains caused by the expansion of the salt or lead in the pot, are additional causes for the cracking of containers. Since changes of shape can be best withstood by ductile materials the containers are usually made of cast steel or of pressed or drawn steel. Cast iron cannot be recommended. The usual arrangement is that of a round pot, with admission of flame or heat at the bottom in a tangential direction, producing a whirling flame, which, by means of recirculation, avoids excessively hot spots or concentration of high tem-

perature in one place. It has been stated by men experienced in salt-bath work that the usual arrangement of admitting heat at the bottom, and providing a vent at the top, is responsible for some of the troubles which have arisen with containers; the pot and the charge, when fired from a cold start, heat up from the bottom and cause the pot to crack or burst, because the top is still frozen solid when the bottom is already liquid and is trying to expand. It has been recommended to reverse the arrangement of flow and to admit the products of combustion at the top, with discharge near the bottom. The standard design of lead or salt pot, with admission of heat at the bottom, is illustrated in Fig. 266. A large producer-gas-fired pot, with development of flame at the

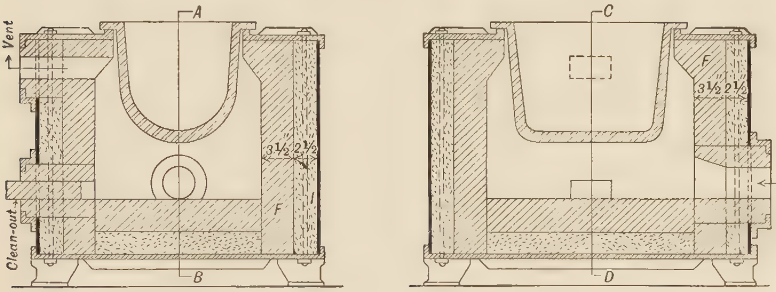

FIG. 266.—Standard design of lead pot.

Note bottom firing, vent at top, and sloping sides of pot.

top and vent at the bottom, is shown in Fig. 267. It is true that this pot is not a lead pot but is an ordinary annealing pot for wire, but the fact remains that the method of directing the flame shown in Fig. 267 could be utilized just as well for a lead or a salt-pot furnace. With the ordinary design of Fig. 266 it pays to keep the salt in large pots molten over night or over the week-end.

The troubles which are caused by the burning out of lead pots or salt pots are avoided by the use of electrically heated salt-bath furnaces. In this type of furnace, which is illustrated in Fig. 268, two electrodes dip into the salt bath and send current through the bath. These furnaces are very satisfactory and have only a very slight disadvantage, namely, that they have to be started by an arc when the furnace is cold, because the cold salt is not a conductor of electricity. The illustration shows how the furnace is started when cold.

Salt baths and lead baths radiate a large amount of heat from their surfaces; in fact, the radiation from the surface is by far the greatest heat loss occasioned by the use of molten baths, and exceeds the useful heat imparted to the steel or other heated material many times over. For that reason they are frequently equipped with devices which conserve the heat when the furnace need not be uncovered for immersing or removing material being heated. For the same reason hoods arranged for carrying salt or lead fumes away from the furnace should not have too strong a draft. Such a draft would cool the hood and the top of the bath by convection, in addition to the continuous loss by radiation.

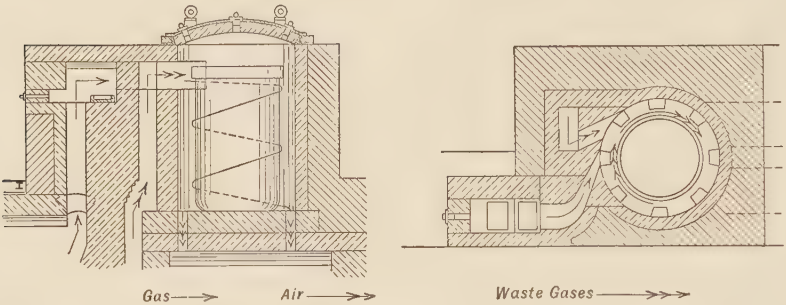

FIG. 267.—Annealing pot for wire. For producer-gas firing.

Note top firing, bottom discharge, and rotary circulation of gases.

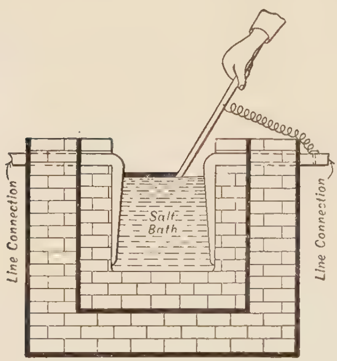

FIG. 268—Electrically heated salt-bath furnace.

Note method of starting operation when salt has solidified, by drawing electric arc.

For some pieces of work rectangular salt baths or lead baths are required. At the corners the troubles arising from oxidation, burning out, and cracking are very much more pronounced, and rectangular pots are therefore avoided wherever possible. They are very common in galvanizing baths and in tinning baths. In these types of furnaces there is a chemical action going on in addition to plain heating, and for that reason they do not strictly

come under the heading of industrial furnaces as considered in these volumes.

In all pot furnaces impinging hot flames must be avoided, otherwise the life of the containers is very short.

Methods of Handling Materials.—To a large extent the various types of furnaces, as far as the handling of materials is concerned, were discussed in Chapter V, under "Labor-saving Devices," and but little remains to be added in the present chapter. Small furnaces and furnaces for irregular work must always be of the batch, intermittent, or in-and-out type. The fixed hearth, of course, has the advantage of simplicity and of low first cost, and is therefore employed almost universally in all general-utility furnaces, that is to say, in furnaces which serve for heating various shapes at various times. It is likewise used for shapes such as large angles, and other material which could be pushed through a continuous furnace, but for which there is not sufficient demand to warrant the cost of a continuous furnace. The latter must have a certain length, to make the continuous feature useful; otherwise, the cost per ton of material handled becomes prohibitive. The decision between the in-and-out type and the continuous type must be made in each individual case.

It is probably safe to say that at least 90 per cent of the *total number* of furnaces in existence are of the fixed-hearth, batch type. When it comes to *total hearth area* of all the furnaces in the world the statement does not hold true by any means, because the large furnaces are usually of the continuous or car-bottom type. In intermittent (or batch-type) furnaces of the fixed-hearth type, a distinction may be made between horizontal heating and vertical heating, that is to say, between hearths on which the pieces are laid down and those on which they are set up on end. Furnaces for vertical heating are usually of the pit type, that is to say, they are depressed below the floor line. In vertical heating for high-temperature work, such as for forging and rolling, the material to be heated must be supported by the hearth. For lower temperatures, such as are present in annealing or heat treating, the material is frequently suspended from the cover of the pit or from a grill near its top. The principal reason for vertical heating is the saving of floor space. In rolling mills, vertical heating of ingots is practiced not only for the saving of floor space, but also for the purpose of allowing gases in the still liquid interior of the

ingot to find their way to the top, instead of to the side, where they would produce cracks. From these circumstances it is obvious that vertical heating is limited to large-scale work, except for special processes, such as heating in salt baths, or vertical heat-treating furnaces. Such furnaces are arranged with access from above, and the material is suspended in the furnace while it is being heat treated. In this case the method of material handling is subservient to the desire for more uniform heat transfer.

As mentioned in Chapter V, the car-bottom type of furnace is used only for material which is too heavy and awkward to be handled economically either by hand or by charging machines. It is particularly useful for long and heavy pieces which must be lifted vertically by a crane.

Batch-type furnaces, with few exceptions, have the disadvantage that the whole furnace full of material must be brought up to heat together. Only in a few cases will it do to have both hot and cold pieces in the furnace at the same time. As a rule, a furnace must be charged completely, and the whole charge must be brought up to temperature at one time. In forges and rolling mills this feature is frequently inconvenient and necessitates the use of several furnaces. For instance, the following rotation is frequently used: one furnace is being charged, one furnace is being heated up, another furnace is being worked out, by which is meant that the material is being removed from it piece by piece and is going to the hammer, the press, or the mill. In some cases as many as four furnaces are used in order to get still greater flexibility. If only one furnace is used the mill men or hammer men are idle while the metal is being heated.

Wherever continuous furnaces can be used, they offer many advantages, including saving in labor and the possibility of gradual heating. The material is brought into the furnace at its coolest end, and gradually progresses towards the hot end. Traveling charging machines or overhead trolleys are dispensed with; the material is always charged at the same place, and is always discharged at the same place. Labor saving thus extends to equipment beyond the furnace, because automatic conveyors can be used both for bringing material to the furnace and taking it from the furnace to the next place in the process of manufacture. The advantages and disadvantages of the various types of con-

tinuous furnaces, as far as labor saving is concerned, were discussed in Chapter V, and need not be repeated here.

Method of Heat Application.—In a comparison of the different methods of heat application a distinction must be made between partial heating and total heating. Partial heating is practiced in heating the ends of bar stock for forging or upsetting, in heating the ends of tubes for welding, and for similar purposes. In such work uniformity of temperature is out of the question, because the temperature tapers down from furnace temperature at one end to barely warm at the other end. It is, however, desirable to have the temperature of that part which is to be worked fairly uniform, so that there is no "bone" in it. Electrical heating, with the heating stock as a resistor, has been practiced of late for this work. It has limitations if the temperatures become so high that the electrodes are injured. In partial heating with fuel firing, the bars project into a furnace, and the products of combustion play all around the part which is in the furnace. That part should not lie on a hearth. Furnaces for this sort of work are known as forge furnaces, bolt-heading furnaces, etc. The old-fashioned blacksmith's fire is an example of this type of furnace.

In cases of total heating, the charge, or heating stock, is intended to receive heat in such a manner as to become heated to a uniform temperature throughout, except in a few special cases (for instance, a "wash heat"). Furnaces can be compared with regard to the method of heat application, and a study can be made of those types which will, in the simplest manner, produce very uniform heating of the charge.

Without any doubt suspension of the work within the furnace, or within the salt bath, gives the most uniform method of heat transfer to the charge. On the other hand, suspension of the charge in the furnace has its limitations. It cannot be practiced for heavy work or for high-temperature heating, because the suspension rod or wire would not be strong enough to hold the heating stock. Besides, the cost of labor would be prohibitive. In consequence, the suspension method is limited to-day to heat-treating furnaces for small work, and more particularly for tools, dies, or similar material. During the World War it was used for heat-treating guns.

From the viewpoint of heat application the next best method

would be that of supporting the charge on piers which are sufficiently high to allow heat to come to it freely from all the walls, including the roof and the floor, of the furnace. This design, however, is too ideal to be practical. To withstand high temperatures piers would have to be made of a refractory material, but such piers are always knocked down in charging or emptying the furnace. In ceramic work the desirable feature of supporting the work on piers is approximated by having it rest on sharp prongs or pinnacles. In metal heating, work heated on trays or in containers has heat supplied from below by having the trays or containers equipped with legs or stools, keeping their bottom surface away from the floor or hearth of the furnace, and allowing radiation and circulation of gases to reach the space between the bottom of the container and the hearth. In the heating of ingots, shafts, rods, bars, and the like, it is a common practice to provide ledges of brick, or stools, upon which the material rests, all for the purpose of allowing heat to enter from below. In high-temperature work, that is to say, if the furnace temperature is between 1900° and 2300° F., these stools or ledges must be made of refractory material, and even then must be quite low, because they carry weight and would be crushed if they were high. In spite of these precautions they have to be renewed quite frequently. In work with lower temperatures, such as for heat treating and annealing, that is to say, with temperatures ranging from 1200° to 1600° F., the stools which support the work are frequently steel castings. They, too, suffer from the combined action of heat and weight, and have to be renewed more often than is to the liking of their owners.

Even with the work supported on stools or ledges it is still necessary to decide how the heat should be applied, and how the furnace gases should be circulated for the purpose of securing most uniform heating. In electrically heated furnaces the question is whether heating elements on the two sidewalls are sufficient, or whether resistors should be arranged also on the rear wall, on the door, under the roof, and in the floor. For the sake of simplicity many electrically heated furnaces are arranged with heaters on the sidewalls only, and it is presumed that the work will be placed on high stools, will be kept at some distance from the resistors, and will be arranged loosely enough to secure uniformity of heating, particularly if a long time is allowed for heating.

On the other hand, electrically heated furnaces have also been equipped with heaters on almost all the wall surfaces. Examples of that type of furnace can be found under "Combustion Devices," Chapter II. Wherever quick heating in a furnace of small size is required, the arrangement of elements on practically all the walls is desirable. Where such necessity does not exist, heating from the side alone has given very satisfactory results, particularly if, as above stated, a sufficiently long time is allowed for heating and if the heating elements are spaced closely near the door. It goes without saying that heating elements not only on the sidewalls but also in the rear, on the door, under the roof, and under the floor, greatly increase the chances for short-circuits or damage to the heaters.

The greatest variety of heat application is met with in fuel-fired furnaces. There we encounter the underfired type, the sidefired type, the overfired type, the type embodying recirculation, and the type with ducts in the walls carrying products of combustion.

Muffle furnaces are, as a rule, underfired; that is to say, the products of combustion come from underneath, pass under the bottom of the muffle, rise along the sidewalls of the muffle, and leave after passing over its top (Vol. I, Fig. 40).

In open-chamber or non-muffled furnaces the underfired type gives apparently the greatest promise of uniformity of heating. It was stated, however, in Volume I, page 204, that the amount of heat which can be transmitted through a hearth is very small, unless the hearth is made of a material possessing the property of high thermal conductivity (such as silicon carbide) or is perforated. In the latter case the material should never rest directly on the hearth, but should be placed on stools for the purpose of preventing non-uniform heating; for it is quite evident that blow-pipe flames and radiation from a bright flame through the openings will cause a spotty heating. This feature is, as a rule, well understood by furnace operators and is taken care of in operation. In that case, heat application comes close to the ideal.

It must be thoroughly understood that the principle of underfiring alone is no guarantee for correct heat distribution. The products of combustion must, in addition, be taken from the combustion chamber and must be led uniformly through the heating chamber in such a way that no "hot spots" are produced.

The principles which must be employed in guiding the gases properly for the purpose of producing greatest uniformity in heat application are discussed in Volume I, under the heading of "Movement of Gases through Furnaces."

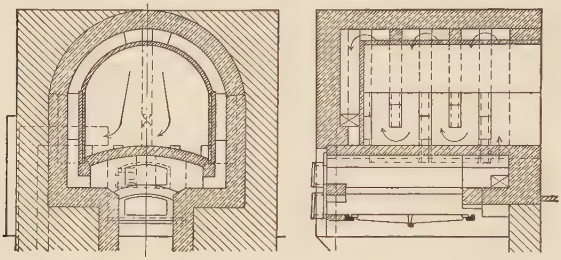

FIG. 269—Underfired muffle furnace for enameling.
Note up-and-down circulation of gases along sides and top of muffle.

Figure 269 shows an underfired muffle furnace for enameling. It will be noted from the arrows that the products of combustion pass up and down between the muffle and the outer wall of the

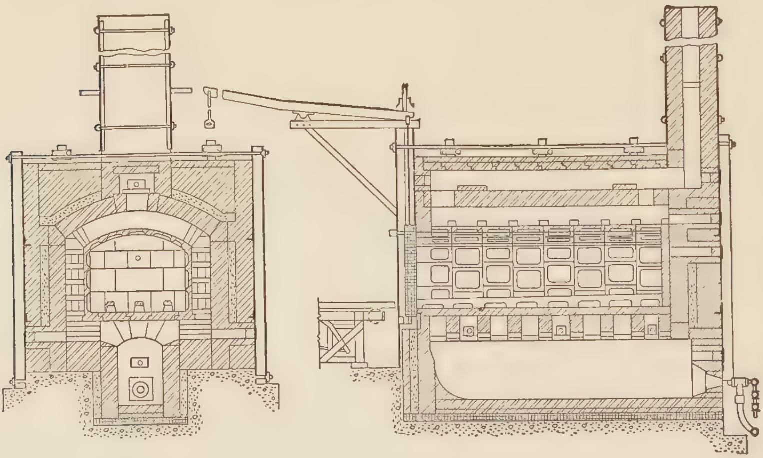

FIG. 270.—Underfired enameling furnace using oil fuel.

furnace before they are discharged to the stack. When coal burned on the grate is the source of heat the above-described method of passing the gases up and down through flues is very generally employed for the purpose of securing uniformity of

temperature. An underfired enameling furnace for oil fuels is illustrated by Fig. 270. On account of the comparatively high heat conductivity of silicon carbide the floor of the muffle is made of that material. It will be noticed that the silicon carbide tiling rests on arches which are thrown across the combustion chamber. The method of regulating the flow of the products of combustion by movable tiles is clearly shown.

Some underfired furnaces are not built with a view to maintaining a hot hearth, but are made underfired for the purpose of placing the combustion chamber in a spot where it will be out of the road. Figure 271 illustrates a furnace of this type, which is rather popular in eastern Pennsylvania. It will be noted that the combustion chamber, which, in this case, is intended to be a temperature reducer and an ash depository for powdered coal, lies far below the furnace, and that the latter is heated solely by the heat in the products of combustion coming up on the side of the hearth.

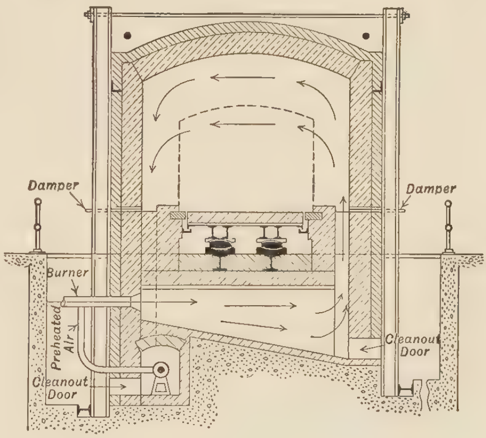

FIG. 271.—Underfired car-type furnace using powdered coal.

With many fuels, and particularly with coal on the grate, underfiring such as practiced in Fig. 271 is frequently inconvenient, in addition to offering no special advantages with regard to uniformity of heat transfer. Besides, mechanical difficulties arise in the supporting of heavy loads on underfired hearths. For these reasons a good many furnaces of the sidefired type are built. These have the combustion chamber or chambers at the side of the main heating chamber and approximately on the same level with it. If that arrangement is used it immediately becomes necessary to find a means of distributing the heat uniformly throughout the heating chamber in spite of the one-sided arrange-

ment of the combustion chamber. A perforated bridgewall, frequently of varying height, is often employed for that purpose. The bridgewall and the openings in it are clearly shown in Fig. 272, which represents a stoker-fired annealing furnace with two combustion chambers side by side. The path of the products of combustion and the manner in which they are intended to circulate, for the purpose of giving uniform heat distribution, are clearly shown in the illustration. In late designs the bridgewall is made, at least in part, of silicon carbide, for the purpose of transmitting radiant heat to the corner, which is more or less dead as far as furnace gas circulation is concerned.

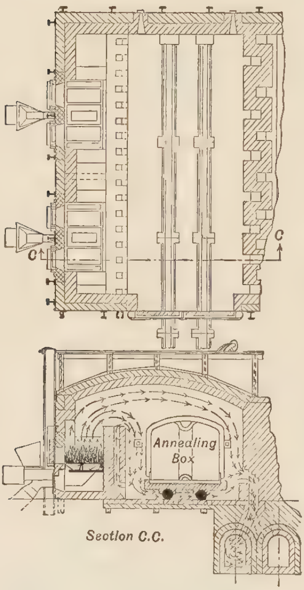

FIG. 272.—Stoker-fired annealing furnace, sidefired type.

Figure 272 shows a good example of a case in which underfiring would lead to mechanical difficulties and is a justification of the existence of the sidefired type.[1] A sidefired furnace with oil as fuel is illustrated in Fig. 273. In this furnace also provision was made for uniform distribution of temperature over the whole hearth as far as uniformity can be obtained with a cold bottom. With oil fuel, underfiring of a car-type furnace results in heavy expenditures without a corresponding gain, except a trifling reduction of floor space. More than any other type, the side-fired furnace depends for its success upon proper circulation of the gases, which in turn depends upon proper velocity of the incoming fuel gas or products of combustion, proper distribution of the inlet ports, and proper distribution of the outlet ports. These details are discussed in the chapter on "Movement of Gases in Furnaces," Volume I. With clean gas as a fuel, with correct furnace design, and with careful control of furnace atmosphere, sidefiring is an unnecessary complication.

[1] If a furnace for annealing sheets in boxes is to be heated by powdered coal, underfiring is better than sidefiring, in spite of the difficulty of carrying heavy loads over the combustion chamber. Compare with Fig. 271.

If combustion takes place directly in the heating chamber the furnace is said to be direct-fired. With oil or gas as fuel, direct firing is quite common for many purposes. A European direct-fired forge furnace for gas fuel is illustrated in Fig. 274. Its simplicity is apparent. On account of this simplicity and of the low cost that goes with it the direct-fired furnace is used whenever that method of heat application produces good results, and occasionally when it is injurious to the quality of the heated product. It is immediately evident that the direct-fired furnace is

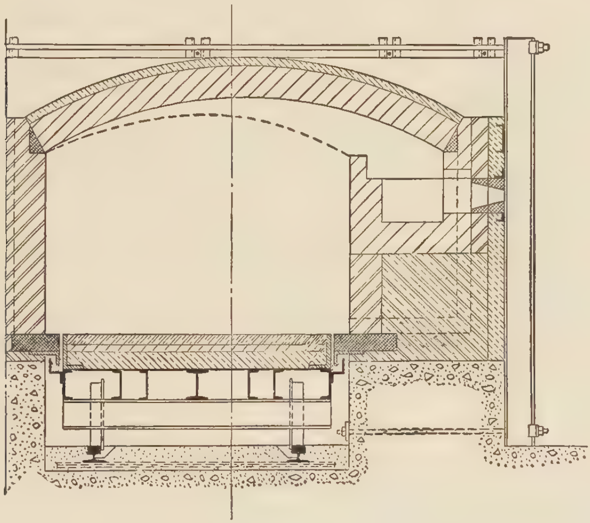

Fig. 273.—Sidefired car-type furnace for oil fuel. A number of combustion chambers are arranged on one of the long sides. In front of each chamber is a bridgewall of varying height.

particularly suitable for any work in which the condition of the surface of the heated material is not particularly important, such as the heating of ingots or blooms for forging and rolling, or the annealing of heavy steel castings, and similar purposes. The furnace type under discussion must be studied in connection with the type of fuel and combustion device used if its field of usefulness is to be defined. The products of combustion of certain gaseous fuels which burn with a non-luminous flame can be directed into the charge, and combustion can take place in direct contact with the charge without local overheating. With oil or

tar as fuel, that procedure produces serious overheating, melting, or burning, because of the intense radiation which is emitted by the highly luminous flame. In consequence, the field of application of the direct-fired furnace is much wider with gas firing than it is with oil, tar, or coal. If high temperatures (2000° to 2400° F.) are to prevail in the heating chamber, direct firing is almost a necessity; if a low temperature, for instance, 1000° F., is to exist in the heating chamber, direct firing is an impossibility. Between these extreme temperature limits lies a range within

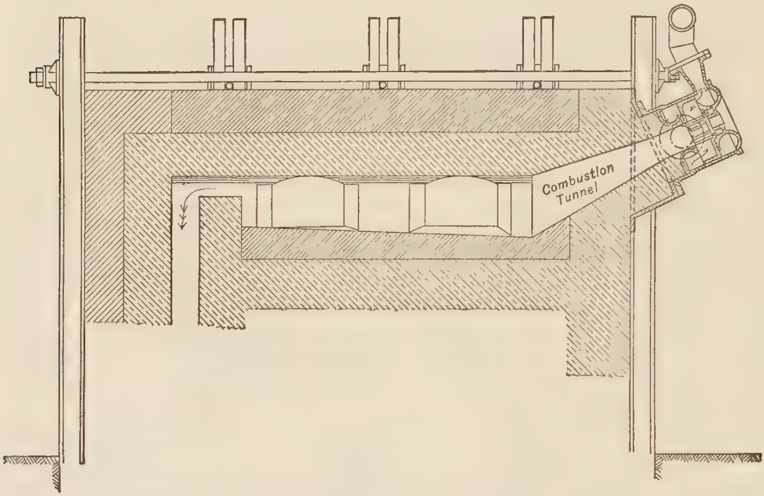

Fig. 274.—Direct-fired forge furnace, gas-fired. Two burners and two combustion tunnels lie side by side. Gas and air are supplied with a slight pressure and are mixed in the burners.

which direct firing becomes less and less desirable as the furnace temperature becomes lower. In this connection the above statements concerning the influence of the fuel and of the combustion device must be borne in mind.

Figure 139 on page 162 represents a direct-fired sheet and pair furnace in which the work is heated to 1500° or 1600° F., and in which practically no scaling is permitted. Direct firing is useful in this case if the furnace is gas-fired and is designed not only for uniform temperature on the hearth but also for correct control of furnace atmosphere. It may not be amiss to state that with underfiring, sidefiring, or overfiring a certain amount of combustion

takes place in the heating chamber and that, in consequence, almost all furnace types are semi-direct fired.

The term "overfired furnace" is commonly applied to that type in which a perforated roof or arch is interposed between the combustion chamber and the heating chamber proper, as shown in Fig. 275. The combustion chamber lies above the heating chamber. The overfired furnace is used only with oil firing and its purpose is solely that of effecting more uniform heat distribution in the heating chamber than would be obtained by direct firing into the heating space. The same effect could doubtless be obtained by a large number of well-distributed small burners; but with oil firing, small burners are disliked by the operators, on account of the many adjustments which have to be made, and on account of the clogging tendencies of small burners. A smaller number of large burners is therefore preferred; and with that arrangement the perforated arch serves a good purpose, inasmuch as it shields the charge from localized bright radiation. In other words, overfiring is designed to meet the conditions created by oil firing, its purpose being to secure a more uniform temperature distribution over the hearths of furnaces working with temperatures of 1200° to 1400° F. This advantage is obtained at the expense of fuel economy, as the large combustion chamber dissipates much heat. Overfiring is never used with gas, because it is not necessary; nor with powdered coal, because it is impracticable for that fuel.

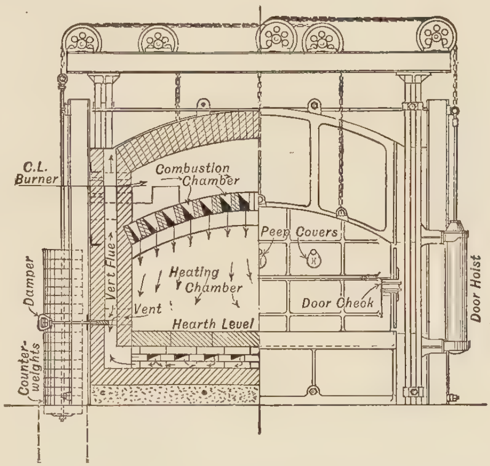

Fig. 275.—Overfired furnace, oil-fired.

Note perforated arch. The products of combustion pass out near the hearth, travel under the hearth, and up a flue on the opposite side.

It is impossible to crowd all existing types of furnaces into the various classifications of the present chapter. Designs are in

existence which lie half-way between some of the classifications, not only in one of the subheadings, but in several of them. As an example, Fig. 276 is offered. It represents a furnace for heat-treating gears, with coal or coke on the grate as fuel. Although the grate lies lower than the hearth, the furnace is not underfired. It cannot be said to be strictly side-fired, and it is not overfired; neither is it direct-fired. The term "side-firing" probably comes closer than any other in the classification of this furnace.

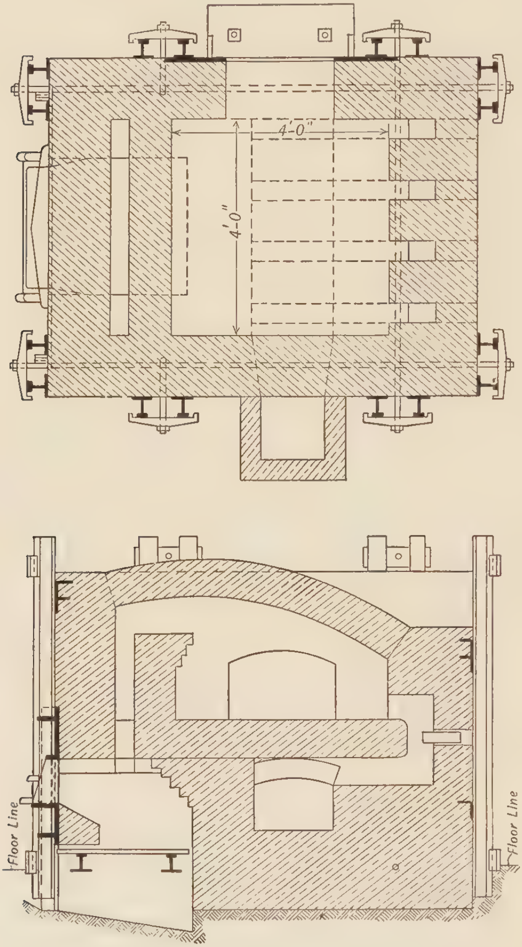

Fig. 276.—Furnace for heat treating, using coal or coke on the grate. This furnace represents a combination of types.

The term "end-firing" is very frequently used in connection with furnaces. It denotes direct firing or sidefiring as applied to one of the narrow sides, which in practice is commonly termed the end. Most continuous furnaces and many forge furnaces are endfired in this sense of the word. Figures 274, and 277 in Chapter VII are examples of endfired furnaces. Endfiring is almost a necessity in continuous furnaces and in regenerative furnaces. It

is also quite common in forge furnaces with several doors. The tendency in any endfired furnace is to create a hot spot near the combustion end and a cooler region away from that end. In continuous furnaces this condition is just what is desired; and in regenerative furnaces it does not do much harm because, after the next reversal, the cool end becomes the hot one. In simple batch-type furnaces the difficulty is mitigated by working with a lazy flame and having combustion extend throughout the length of the furnace. The effect which a lazy flame has upon furnace atmosphere and upon scaling of the charge was discussed under "Control of Furnace Atmosphere," in Chapter IV.

In the early part of this chapter it was stated that there is scarcely any limit to the number of types of furnaces that can be designed by combining the various elements cited under the different classifications. It is impossible to make anything like a complete comparison of all the different types of furnaces which can be designed and operated as a result of the various combinations. It should again be noted that certain types of furnaces which are very useful with one fuel may become inefficient or impractical if a different fuel is used. Moreover, of two identical furnaces fired with the same fuel, but equipped with different combustion devices, one may do well while the other may do poorly. Going still farther back along the line, two furnaces equipped with the same combustion devices, and fed with supposedly the same fuel, may show great difference in results, on account of errors in design and installation of the auxiliaries. Furthermore, a type of furnace which will give excellent results when attended by a careful and skillful heater may give very poor results if attended by an inexperienced or careless heater. It is claimed that electrical heat is free from these accidental variations.

The variables are so numerous, and the effect of seemingly small changes in the guiding of the products of combustion, or of other apparently unimportant factors, is so great that those who have spent weary hours with furnaces will understand the superstitions of some of the old-time heaters who claimed that a furnace would never work right if it did not face due northeast or that in order to burn natural gas you had to have natural air.

To carry the critical comparison of furnace types any further would unduly lengthen this chapter without bringing forth any new principles.

CHAPTER VII

SELECTION OF FUEL AND OF FURNACE TO SUIT PLANT CONDITIONS

General Methods of Selection.—While rules of a strictly engineering nature can be laid down for the general comparison of fuels and furnaces these rules lose much of their importance in specific cases, because economic considerations and fortuitous circumstances enter.

Not so many years ago it was customary to compute the thermal efficiency of various furnace types for different fuels, or else to determine " the available B.t.u. " for each fuel, and to compare them with regard to price. That fuel which furnished the highest number of heat units for a given cost was selected as best. That procedure, however, had to be given up in spite of its seemingly mathematical certainty, because it neglected the economic considerations mentioned above, the form value of the fuel, the human element, and accidental circumstances existing in each specific case. While this crude method of selecting fuels solely on a B.t.u. basis has largely been abandoned those who are confronted with the necessity of selecting new furnace equipment often express a desire for some sort of mathematical formula, slide rule, or alignment chart, in which the variables can be substituted and from which the answer can be obtained with unfailing certainty and precision, determining the correct source of heat energy and the correct type of furnace. It is needless to say that this much-desired formula will never be devised.

On the other hand, it should be quite possible to evolve a logical process of reasoning which can be followed, with some variation, in each individual case. The present chapter is an attempt to evolve such a process. It is also intended to show, by means of examples taken from actual practice, to what extent accidental circumstances determine the selection. In the present chapter some facts which were already explained must necessarily be repeated, because a correct decision cannot be made without a

sound knowledge of the whole field of fuels and furnaces. Like the previous chapter, the present one touches upon a delicate subject, because manufacturers of equipment for one type of fuel, or those who feature a certain type of furnace, may feel that the author has discriminated against them, when actually no such intention existed in his mind.

If a manufacturer needs a furnace he can select the equipment in various ways. (1) He may consult a commercial register giving the names and addresses of manufacturers of furnaces, or he may get the information from the advertisements in the technical press; he will then state his requirements in a general way to the furnace builders, and make his selection from the bids and designs submitted, being guided by the advice which the sales engineers of the manufacturers volunteer. (2) If he prefers, he may take his problem to a consulting engineer, who will pick out the correct equipment for his case. (3) Or, finally, he may go to workshops where similar work is being done, observe furnaces and results obtained in actual operation, and select that equipment which promises the best all-round results when applied to his own conditions. The last course is very frequently followed in case of important furnaces, because the manufacturer is certain that he will not meet with any unpleasant surprises, delays, or experiments, if he installs a furnace just like the one which has been working successfully for years in some other plant. On the other hand, this method of procedure retards progress if followed too slavishly. New types of furnaces, new sources of heat energy come up from time to time, and someone must be the first to try them and introduce them. The ultraconservative man, who never installs anything except that which someone else has been using successfully for years, may find that, in a year or two, he has equipment which is very much out of date, and may regret his conservatism.

If the new furnace is to be an important one it is advisable to combine all three methods. If a very small furnace is to be purchased it does not pay to go to much trouble, because another furnace can readily be installed if it is found that a mistake has been made in the selection of the first one.

A rule which can be utilized in the selection of fuels and furnaces for almost any plant is as follows: the cost of finished, perfect material must be lowest in the long run, and that furnace

and fuel should be selected which will, in the heating of the material, contribute most towards lowering the cost of finished, perfect product. That very general requirement includes many separate items, among which are the following: the cost of a given quantity of heat, for instance, in cents per million B.t.u. during the life of the furnace; the cost of delivery of fuel to the furnace and of removal of waste products, such as ashes; wages to heaters, and cost of supervision of furnace; availability of fuel, and cost of changing over from one fuel to another; cost of shut-downs due to lack of orders (payroll and service charge to be carried during shut-down); cost of charging and emptying furnace, of labor in handling materials, of heat losses of furnace; cost of furnace maintenance; cost of rejections or of reduction in grade of finished material; cost of scaling and burning; costs of processes which remove defects originating in the furnace; cost of delays due to interruption of fuel supply, to adjustment of burners, or to furnace troubles; cost of equipment which is necessary to insure regular fuel supply; cost of reduction in output due to improper location of furnace in factory and due to the effect of excessive heat radiation or obnoxious fumes on the workmen; fixed charges for furnace investment, including that of auxiliaries, foundation, and stack; adaptability of furnace to changing conditions.

As above stated, the cost of all these items must be a minimum in the long run. It is, of course, utterly impossible to write an equation connecting all these variables or even one-half of them. What is needed in each particular case is, first, a careful weighing of the effects of these variables, and, second, a good guess based on this study, backed up by sound judgment and experience.

Selection of Fuel or Heat Energy to Suit Plant Conditions.—In a few cases the nature of the source of heat energy to be used will be positively given without the shadow of a doubt. Such cases will, for instance, exist in steel plants having by-product coke ovens, with ample coke-oven gas available for heating furnaces. In localities with very cheap water power, electricity as a source of heat for industrial furnaces is adopted in preference to other sources of heat energy. There are still some regions in which natural gas is available in abundance and at a low rate, and in those localities it will doubtless be adopted as fuel for new industrial furnaces, not only because of its cheapness, but also because of its cleanliness and other valuable properties.

Such clear-cut cases are the exception, however, rather than the rule. In by far the greater number of cases it will be necessary to weigh carefully the advantages of the different fuels, and to arrive at a decision only after thorough study. Probably the best method is to take the list of fuels, as given in Chapter VI, and to arrive at a narrowed choice between two or three, by elimination of all the rest. This process of elimination will be materially assisted by putting on paper the effect which the fuel or other source of heat energy will have upon the various items affecting costs, as listed on page 354 of the present chapter. In this work the effect of the various available combustion devices must be kept in mind. Oil flames, for instance, when produced by a poor type of burner, when supervised by a careless or unintelligent heater, and when fed with fuel of fluctuating temperature and pressure, will burn or scale or even melt the charge, or may mark it badly by causing partly burned fuel particles to fall upon it. The same oil, when burned in a combustion device of good design, fed at a uniform temperature and pressure, and supervised by a skillful and careful heater, may result in a perfectly heated product with practically no rejections. It may be inferred from this statement that the selection of the source of heat energy involves a thorough knowledge of the combustion devices available for the various fuels, of their action, and of the type of furnace to which they will be applied.

In the elimination of the different fuels and sources of heat energy, and in the narrowing down of the choice, the size of the furnace and of the plant must be considered. In a small, isolated furnace, city gas or electrical energy, which are high-priced per unit of heat delivered, may be by far the most economical, because they involve practically no equipment and no attendance except that required for the furnace proper. In large plants, on the other hand, it may be economical to install and operate, even at great expense, equipment for handling liquid fuels or for producing gaseous or powdered fuels, because such equipment makes it possible to use very much cheaper fuels than could otherwise be utilized. In such cases the use of a very cheap raw fuel will overbalance the fixed charges and the cost of labor used for operating the fuel preparation plant, with the result that the total fuel cost will be very much below that of using city gas, natural gas, or electricity.

In plants already equipped for the use of a particular fuel it

often happens that a new furnace, which would burn some other fuel more advantageously, is added to the installation. Nevertheless, the fuel already serving the old furnaces is burned in the new one, because the installation of equipment for using a new fuel would cause much outlay and great changes in methods of operation.

It is manifest that, in the conditions influencing the selection of the fuel, very few plants are alike, and that each new case requires careful study, if the best results are to be obtained in the long run. Specific cases of selection of fuel are discussed in the examples which are given below.

Selection of Type of Furnace to Suit Plant Conditions.—In the selection of a furnace type for a specific case it is advisable to look over the list of types given in Chapter VI and to study the effect which each will have upon the items affecting costs, as mentioned on page 354 of the present chapter.

In this connection one of the greatest difficulties lies in the fact that very frequently the person contemplating the installation of a furnace does not know, at the time of the selection, what material is to be heated in the furnace. It is by no means a rare occurrence for a furnace or a group of furnaces to be bought for the purpose of heating one kind of material, and used, after six months or a year, for heating an entirely different kind of material. Builders of furnaces frequently suffer from this condition, because, in many cases, visitors who inspect the plant are told that the furnaces are "no good," when, as a matter of fact, they were most excellent for the work for which they were intended, but not for the entirely different purpose for which they are used. Law suits are known to have arisen from the fact that the work of the furnace was changed before the last payment had been made. If an intending purchaser of a furnace is not certain about the kind of work which it is to do, a general-purpose furnace should be installed in preference to a special-purpose furnace, even though the general-purpose furnace may be more wasteful, for one class of work, than the highly specialized furnace would be.

So many misfits originate from the lack of a clear conception, on the part of the purchaser, of the possibilities of various furnaces, and from misunderstandings between the purchaser and the sales engineer, at the time of negotiation for a contract, that any steps towards clearing up doubtful points at that time should be taken

whenever and wherever possible. Valuable assistance in accomplishing that end was furnished in the December, 1923, number of *Fuels and Furnaces*, in the form of a data sheet, which is reprinted herewith.

DATA SHEET

Name of Firm. . . . .

Address. . . . .

Please fill in as many of the data as you conveniently can; a few may seem irrelevant to you, but they will result in a more complete and more satisfactory proposal; complete answer *at this time* will avoid delay, expense, unnecessary correspondence, and misunderstandings. If you do not understand the meaning of a question ask us about it in your letter.

Important

1. Is this a preliminary inquiry? Yes. . . . . . No. . . . . .
   For general information purposes? Yes. . . . . . No. . . . . .
   For estimating purposes? Yes. . . . . . No. . . . . .
2. Are detailed proposals wanted at this time? Yes. . . . . . No. . . . . .
3. Do you wish to have a representative call? Yes. . . . . . No. . . . . .

Nature of Operation

Underline the correct one, or cross out those which do not apply.

4. Baking, japanning, drying, bluing, drawing, tempering, normalizing, annealing, bright annealing, burning, case hardening (carburizing), pressing, forging, rolling, welding, melting, refining. Other processes
   . . . .
5. To what temperature is the material to be heated? . . . . . . ° F.
6. At what temperature does material enter furnace? . . . . . . ° F.
   Material to be heated (nature and quantity). . . . .
7. Uniformity of temperature desired in heated charge. . . . . . ° F.
   Temperature difference allowable between hottest and coldest part of heated stock. . . . . . ° F.
9. If possible, give a *complete* cycle of operations (preferably for the period of one week). . . . .
   (time of heating, time of soaking, time of cooling, etc.). . . . .
   . . . .
10. Length of time during which furnace or oven can be in operation each day. . . . . . hours.
11. Nature of material to be heated (steel, brass, earthenware, etc.)
    . . . .
12. Weight to be heated (or melted). . . . . . pounds per day of. . . . . . hours.
13. Dimensions of largest piece. . . . . .weight. . . . . . pounds.
14. Average dimensions. . . . .
15. Maximum thickness of piece to be heated. . . . .
    Average thickness of piece to be heated. . . . .

TYPE OF FURNACE, OVEN, KILN, ETC.

Is there any furnace (or oven) equipment used in the plant to which the new equipment must conform? Yes...... No......

If so, describe the type..

Is the stock sufficiently regular to allow automatic handling? Yes...... No......

Do you prefer a certain type of furnace, or shall we select the type?..

If you prefer a certain type of oven, furnace, or kiln, describe it (vertical, horizontal, conveyor type, rotary, car type, muffle type, number of doors, recuperative, regenerative, etc.)..

If material is to be handled on truck, car, conveyor, or hanger, describe the handling device (including pans, core plates, etc.) and give its weight

....

HEATING

Can we select the fuel or source of energy best suited for the purpose?......

Do you prefer a certain fuel or source of energy?......................

If the latter, which fuel?..

What fuel or source of energy is available and at what price? Coal (bituminous, semibituminous, anthracite, powdered), coke, heavy oil, light oil, tar, raw producer gas, cold clean producer gas, mixed gas, coal gas, coke-oven gas, water gas, natural gas, blast-furnace gas, electricity.

Price of available fuels (gas and electric rates can be obtained from public utilities corporations)..

CONTROL

Are we to figure on automatic temperature control?..................

What kind of furnace atmosphere is desired? Reducing, neutral, oxidizing?..

AUXILIARY EQUIPMENT

What source of electric current is available?..........................

Direct current......volts. Alternating current......cycles.

Single-phase, two-phase, three-phase?................................

Water pressure available......pounds per square inch.

Air pressure......pounds per square inch.

Oil pressure and temperature.......................................

Gas pressure..

Steam pressure..

LOCATION

Is location of furnace to be fairly permanent or will it probably be moved after a few years?..

Can furnace be sunk into floor, if that should be desirable? Yes...... No......

What floor space is available? ......feet long ......feet wide.

What height is available? ......feet.

Economy

Is low first cost desired (at the expense of fuel economy and labor economy)? Yes...... No......

Construction and Erection of Furnace, Oven, etc.

What are the conditions at site with regard to unloading and storage of material required for proposed furnace?..............................

What material (if any) may be purchased locally for the proposed furnace, oven, etc.?...

Sketches

Give sketches of pieces to be heated, of building where furnace is to be placed, of surrounding objects. Even the roughest sketches will be of assistance.

This questionnaire may seem too lengthy, and may appear to be altogether too complete. Nevertheless, plant conditions may exist which have not been taken care of in the questionnaire, such as the presence of a powerful steam hammer close to a furnace. Vibration of the ground, caused by the steam hammer, may necessitate a furnace construction and a furnace binding which would not be required under ordinary conditions. The presence of water in the ground may also restrict the choice between furnace types. All of these circumstances again emphasize the fact that only the most complete study of local conditions can serve as a guarantee against poor results or high costs in industrial heating.

Examples of Selection of Fuels and Furnaces; Forge Furnaces.—It is manifestly impossible to discuss and enumerate all the different local plant conditions which can affect the selection of the proper source of heat energy and of the type of furnace. On the other hand, it is quite feasible to select a few processes and plants and to show, by means of examples, the local conditions and the processes of reasoning which, in specific cases, have led to the adoption of certain fuels and of certain furnace types. In the study of these examples care must be taken not to draw the hasty conclusion that, under apparently similar conditions, the same kind of fuel and the same kind of furnace would always be the best, because, in the new case, a seemingly minor difference of local conditions may affect the selection to such an extent that what was quite the right thing in one plant would not be correct at another place or at another time.

As a first example of the effect which local conditions have

upon the selection of fuels and of furnaces the case of two forging plants in an iron and steel district will be considered. One of them, which will be called the *A* works, is a forging plant, pure and simple, and turns out high-grade forgings of a great variety of classes. The other plant, which will be called the *B* works, is an adjunct to a large machinery manufacturing concern, and is run mainly for the purpose of producing the forgings which the manufacturer of heavy machinery requires. Coal is the basic fuel in the district in question, and both plants, although built years apart, originally burned coal on the grate, utilizing the waste heat of the forge furnaces in waste-heat boilers. In the *A* works, which is the older plant of the two, the waste-heat boilers were used for a number of years, but were finally abandoned, and the furnaces were rebuilt for oil, while a new central boiler plant was built for furnishing steam to the hammers and presses. Oil was not adopted immediately; the first fuel considered, when the decision was made to rebuild the furnaces and to abandon coal on the grate, was powdered coal. The owners of the plant went so far as to order the powdered-coal equipment, but were deterred from using it by visiting another forge using powdered coal on a day when the powdering equipment was working poorly and when there had been no wind to speak of for several days. There were ash deposits everywhere, and the owners of the *A* works immediately decided that, while powdered coal would do for rough work and for a forge located out in the woods, it would never do for city use or for fine work.

In the *B* works it was found that, on account of the forging of heavy ingots and long pieces which required cold tongholds and which had to project out of the furnace, the doors had to be partly open all the time; and such a large part of the products of combustion was discharged through the doors into the shop that very little was left for the waste-heat boilers. Besides, the stokers were of a type which is well adapted to boiler work, but is unsuitable for industrial furnaces. In consequence, the roofs over the stokers burned out so often that continuity of operation was almost impossible. For that reason the furnaces were rebuilt for oil, and the stokers were placed under the boilers, where they did very well. Later on some new gas wells, furnishing considerable quantities of natural gas, were drilled in the neighborhood, and natural gas was adopted as a fuel. It has served for several

years and is still being used at the present time, that is to say, at the writing of this chapter.

On account of the great variety in the kinds of work to be done and in the size of the pieces furnaces of the batch type, or intermittent type, were selected. The continuous type was out of the question. In changing over from coal to oil the system of endfiring the furnace, so common with coal firing and illustrated in Fig. 277, was retained. It is characteristic of a furnace with several doors that it requires a gradual heating up of all the material in the furnace at one time. This property has been

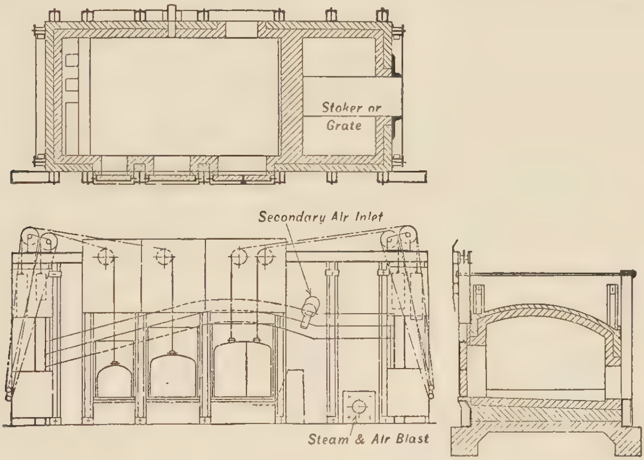

Fig. 277.—Endfired forge furnace for large ingots.

found very beneficial in that section of the *A* plant which produces a variety of work, particularly small work. The same feature was found to be quite burdensome in the *B* forge, where fewer but larger ingots were heated. In consequence, the endfired furnace with several doors was replaced in the *B* works by another type. Similarly, a few one-door furnaces were built in the *A* forge plant for heavy ingots. Regenerative heating was first tried in the *B* works, but was discontinued after a while. Forging ingots are frequently of a composition that will not stand rapid heating. In consequence, the furnace, including the regenerators, must be cooled down to a safe temperature before a fresh ingot is placed in it. This action cools the regenerators to such an extent that, for quite a while, they do not add anything to the perform-

ance of the furnace. Besides, with an open door, that is to say, with door openings at both sides of the ingot which projects out of the furnace, and with a horseshoe-shaped flame, so large a fraction of the products of combustion passes out under the door that very little is left for use in the regenerators. Finally, it was found that natural gas and air did not mix well, so that the flame did not develop properly in the furnace.

Vertical heating, such as is practiced in soaking pits, was considered, but was not introduced on account of the varying lengths of the ingots. It would also have caused difficulty in the handling of ingots which have to be forged out to considerable length. In this case, one end has to be heated first, and the other end later, after the ingot has already been forged out to a certain extent. For that reason simple furnaces heated by premixed gas and air were adopted. Although the feature of regeneration, which is supposed to save heat, was discontinued, the cost of heating per ton of ingots was lower after the simpler and apparently more wasteful type of furnace had been installed. This is not an argument against the regenerative principle, but shows that, under the conditions existing at the *B* works, it was out of place.

The simpler type of furnace which was installed after regeneration was discontinued is diagrammatically shown in Fig. 278. Two heating chambers are arranged side by side. The heat enters near the door in one furnace, swirls around the ingot, and preheats the ingot in the next chamber. This fuel-saving arrangement was also found to be ineffective, inasmuch as heating and forging schedules could never be worked out to suit this furnace. In consequence, the opening between the two heating chambers was closed, outlets were provided for the products of combustion in the most convenient, although not the best, location and each chamber was operated separately. Finally, two burners were arranged for each side, for the purpose of getting a more uniform heat along the body of the ingot. Recuperators were often thought of, but they never materialized, because of the irregular forging schedule in the plant in question. On the other hand, recuperators were installed and were found to be a paying investment in the *A* plant, for the simple reason that here the heating and forging process is much more regular, and therefore the investment for a recuperator pays higher dividends than it would do in a forge with sporadic operation.

In one of the preceding paragraphs the statement was made that continuous furnaces could not be considered in either of the two forge shops designated as A and B, on account of the great variety of work which passes through them. On the other hand,

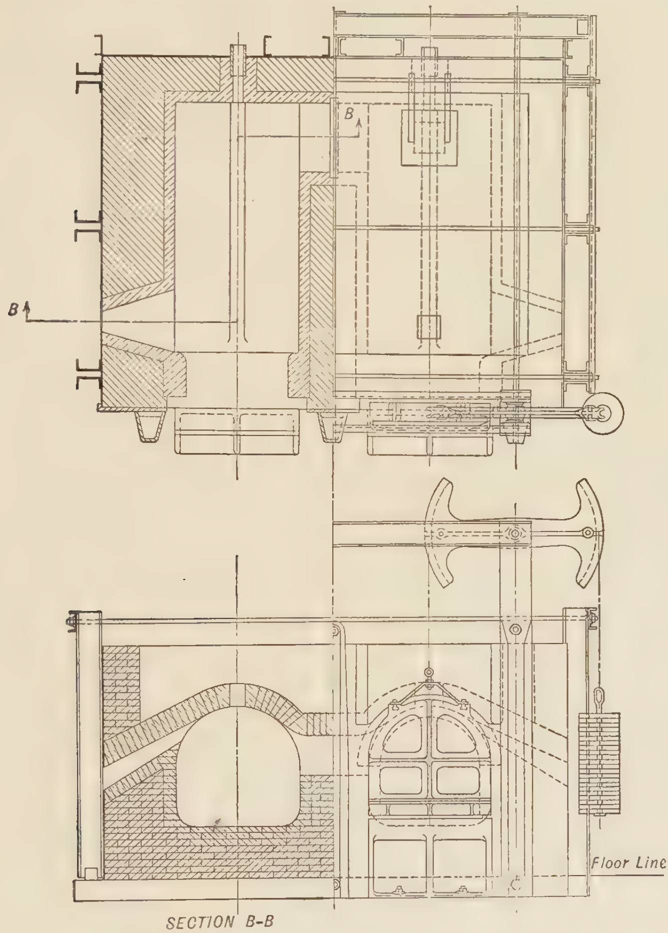

FIG. 278.—Double-chamber forge furnace arranged for preheating.

the experience of a plant making tires for railroad wheels proves that continuous heating in forge work is advisable and economical if there is a sufficient amount of duplication in the work. In several shops where tires are made the ingots are heated in continuous furnaces and are given their first hot working under a

forging press. In one tire plant ingots up to 23 inches in diameter are pushed over water-cooled pipe skids, to a fore-hearth, where they are turned by the manipulator and allowed a certain soaking period. In several continuous heating furnaces for ingots, in tire plants, powdered coal is used as fuel and is giving a very uniform heat. On account of the more or less rough nature of the work deposits of ash on the ingots do not produce any harmful effects. The ashes drop off with the scale when the ingot is under the press.

Sheet and Pair Furnaces.—The requirements of the material being heated, the availability of the fuels that are suited to the purpose, and plant conditions have combined to bring about the evolution of certain types of furnaces for the heating of sheet bars, which are commonly called pairs, and for the heating of partly finished sheets, which are called break-downs. The type of furnace which has been developed for this work is so clear-cut, and the requirements are so specific, that a study of the history and evolution of this type of furnace will doubtless be of interest and will serve to explain the influence of plant conditions upon the design and operation of furnaces.

Steel sheets and tin-plates are rolled from sheet or tin-plate bars about 8 inches wide and of a length equal to the width of the sheets which are to be rolled. The thickness of the bars varies from $\frac{3}{8}$ inch to about 1 inch, depending upon the length and thickness of the sheet which is to be produced from the bar. The sheet bars (which are also frequently called pairs, because two of them are put together after they have been rolled out during the first passes) as well as the sheets themselves, are exposed to the air for a considerable time during the rolling process, and would scale excessively if the temperature were high. In consequence, sheets are rolled just above the critical temperature, that is to say, at about 1400° to 1450° F., while sheet bars are rolled at a temperature of 100 to 150° above that of sheets. The low rolling temperature results in extremely great forces between sheets and rolls, reaching 50,000 pounds per inch of width of sheet. At that high pressure any uneven scale which may be formed is rolled into the sheets, and mars the rolls. On the other hand, a thin, uniform scale is necessary, because the sheets, which are rolled in packs, will stick together if clean, metallic, red-hot surfaces are in contact. Finally, a loose or a plastic scale, such as might be caused by overheated oxide or

sulphide, sticks to the cooler rolls, forming pinnacles on them and marring the sheets to such an extent that they have to be sold as second or third quality.

In addition to the requirements stated in the preceding paragraph there are others which furnaces for heating sheet bars and sheets must meet. They may be summarized as follows: (1) The furnaces must suit the mill layout and the method of rolling. (2) The sheets must be free from ashes or soot or any other foreign material. (3) The material must be heated uniformly all the way through; that is to say, the sheets at opposite sides of the pack must have the same temperature, and the inside of the sheet bars must have the same temperature as the outside. (4) A thin layer of oxide, adhering with uniform firmness, must be formed; this layer must be of such a nature that it stretches with the sheets in the rolls without cracking.

The old Welshmen who brought the knowledge of the art of rolling sheets to the United States apparently were well acquainted with these requirements. In any event the equipment which they brought along made possible the rolling of very good sheets. Changes and improvements were made from time to time; some of these so-called improvements, however, resulted in a poor grade of sheets, and were later abandoned. The result is that the sheet and pair furnace of to-day is not very different from the design which was originally brought over to the United States.

The different requirements will now be taken up in order:

(1) Sheet mills are strung out in a long line, many mills being driven by one motor or one engine. At each mill the sheet bars are heated in one furnace, are dragged across the working floor to the mill, and are rolled, first singly, and then in pairs. The furnace in which they are heated is known either as a sheet bar furnace, or, more commonly, as a pair furnace. When the pairs have been rolled out to a certain length they are, in many cases, doubled, and reheated in the sheet furnace, which must likewise be located near to the mill. The customary arrangement of one unit is shown in Fig. 279. The sheets are then rolled to their final length. If thin (light) sheets are to be rolled the pack is again doubled, reheated, and then re-rolled. After the final rolling the sheets which have been rolled in one pack are opened or stripped apart.

From the description of this process, and from the arrangement of the mill, it is quite evident that the operating doors of both furnaces must face the working floor side by side, or else be just around the corner. As a rule there is very little room between the furnaces.

(2) No loose oxide or scale must be formed, because it would spoil both the appearance of the sheets and the surface of the rolls. This requirement means that the furnace atmosphere must be neutral or slightly reducing, no air being permissible in the gases of combustion. Loose, porous scale absorbs and holds

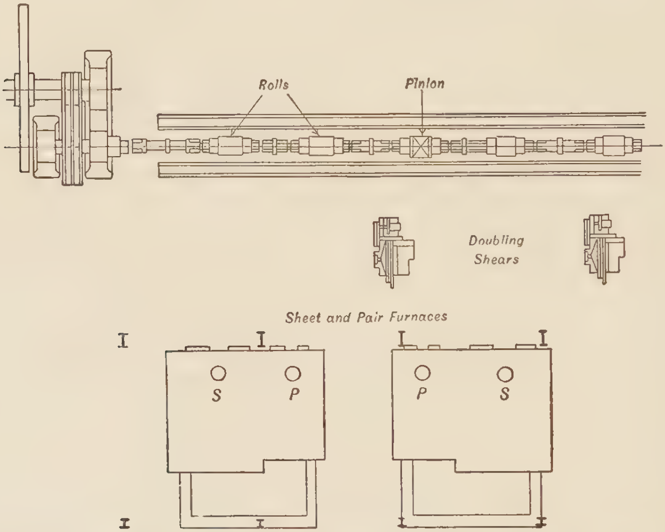

FIG. 279.—Location of sheet and pair furnaces with regard to rolling mill. S = sheet furnaces. P = pair furnaces.

products of combustion by capillary attraction, particularly if the inside of the packs is not heated to the proper temperature. This sort of scale breaks in the rolling process, allowing streaks of pure metal to come in contact with each other and to be welded together under the pressure of the rolls. If the scale contains too much gas it causes loose rolling and jumping or pinching of the sheets. It is thus productive of "stickers" and "wasters."

(3) The necessity of keeping ashes and soot away from the sheets needs no comment, because any foreign, scratchy material spoils the appearance of the sheets. Coarse ashes injure the rolls also.

(4) The requirement that the sheets must have the same temperature at both sides of the pack is easily understood. If one side is colder than the other the pack will either curl or roll loose, both of which are undesirable. If the outside of a sheet bar is hot, while the inside is cold, the pressure between steel and rolls becomes excessive. The rolls are marked, and the surface of the sheets suffers. Besides, rolling below the critical temperature causes a cold flow and hardens the material.

(5) The requirement that a very thin layer of magnetic oxide must be formed has quite frequently been overlooked, but is nevertheless very essential. The sheets must not have clean metallic surfaces, because such surfaces will stick together on account of the enormous pressure between the rolls. On the other hand, the oxide skin must be so thin and so even that it will stretch with the sheets without cracking. The oxide coating must stick firmly to the sheets. Experience seems to indicate that the right kind of oxide skin cannot be formed unless there is some water vapor present in the furnace gases. The reaction is supposed to take place in accordance with the equation,

$$3Fe+4H_2O=Fe_3O_4+4H_2.$$

If that assumption is correct, sheets cannot be heated with a coke fire, unless steam is blown under the fire, or natural gas is burned with the coke. Whenever bituminous coal is burned properly water vapor is present in the flue gases, with little or no free oxygen.

On the basis of these requirements a study can be made of the suitability of various types of furnaces for sheet mill plants.

Figure 280 shows a combination sheet and pair furnace of a type which was, at one time, widely used, and of which many are still in operation. The furnace is hand-fired. The flame spills over a bridgewall, hugs the roof of the pair furnace on account of its lightness, strikes the partition wall, drops down to an opening just above the hearth, rises over a second bridgewall, hugs the roof of the sheet furnace, and passes out through ports near the doors at the hearth level. The advantage of this furnace type lies in the fairly good utilization of fuel. The pairs (sheet bars), which need a higher temperature than the sheets, are heated by radiation from the hottest flame. However, the

furnace has its disadvantages. It is almost impossible to regulate the temperature of the sheets and of the sheet bars independently of each other. Furthermore, air enters the pair furnace, unless pressure is maintained in it, at the level of the hearth. The small difference of levels between the hearth and the grate prevents the existence of pressure in the pair furnace, unless the rate of heating is very low. In this combination furnace the combustion chamber is located farthest away from the mill. The openings in the sheet furnace, that is to say, the right-hand compart-

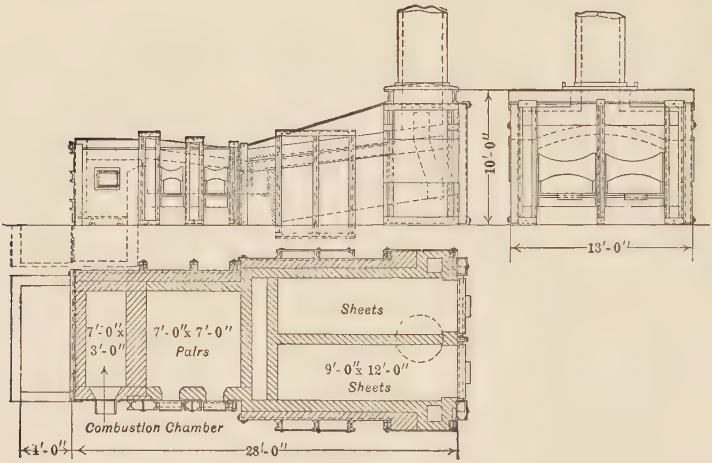

FIG. 280.—Combination sheet and pair furnace.

ment in the drawing, are very handy in their location to the mill, but the doors of the pair furnace are some distance away from the mill, which means that pairs must be dragged a greater distance from the furnace to the mill. In that longer distance some oxidation of the pairs occurs, but it is small in comparison to the oxidation which occurs by leakage of air into the pair-heating chamber. A slight pressure under the grate helps to overcome air infiltration; but even with that expedient it is rather difficult to delay combustion in such a manner that a uniform temperature is obtained over the whole hearth of the sheet-heating chamber. These reasons have doubtless contributed towards the gradual disappearance of this type of furnace from modern sheet mills.

If the heating of pairs and of sheets is to take place in separate heating chambers the question arises whether it would not be better to fire the pair-heating chamber and the sheet-heating chamber independently, in the manner illustrated in Fig. 281. The furnace represented by this illustration, either hand-fired as shown, or else equipped with stokers, is probably the most widespread type of sheet and pair furnace in the United States today,

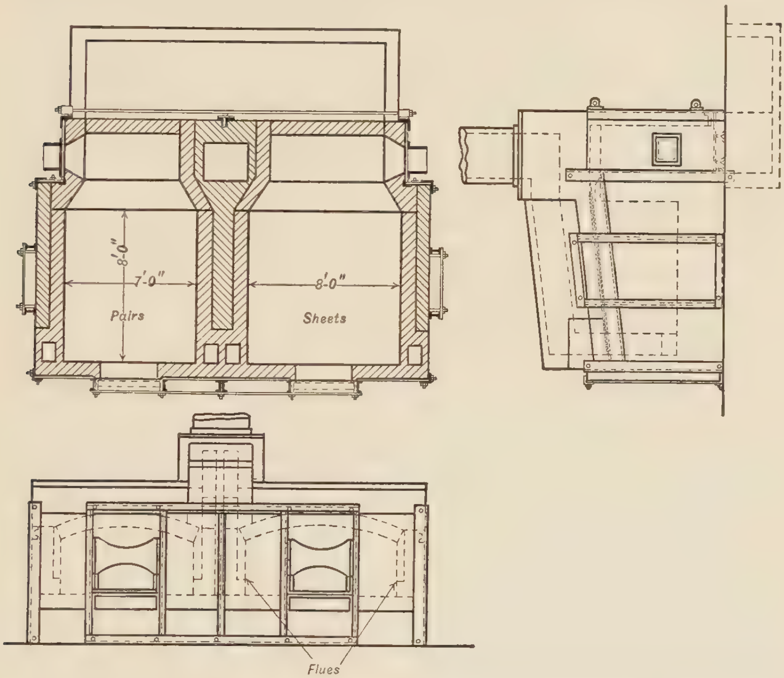

Fig. 281.—Sheet and pair furnace with independently fired heating chambers.

although it is in the minority in new installations. Both chambers can be regulated independently, and fires can be cleaned at different times. There is only one stack with one damper for both grates, but bricks can be put into the ports of either furnace, and the different draft conditions can thereby be regulated.

Up to the present time, space limitations, as well as the shape and thinness of sheets, have prevented mechanical handling in the furnace. Sheet bars, on the other hand, can be pushed through a furnace by a pusher. Furnaces embodying this feature are

shown in Figs. 282 and 283. In both types the purpose was evidently that of securing a gradual and uniform heating of the pairs and of saving labor. In the former furnace the sheet bars are laid in inclined piles on a rack outside the furnace, between the latter and the pusher. A motor-operated pusher shoves the bars into the furnace and pushes all of the other piles ahead. Alternate rows of sheet bars slant in different directions. If those on the outside rack incline upward to the right as at *A* the bars in the charge ahead incline upward to the left as at *B*. The sheet bars cross each other at the point of contact between succeeding charges, with the result that climbing or piling is positively prevented. The bars are finally pushed on to a sort of fore-hearth, where the heater can spread them out for the purpose of obtaining an absolutely uniform temperature. The very existence of this fore-hearth seems to indicate that the bottom bars of each pile are not heated to the same temperature as the top bars, and that the fore-hearth is desirable for the purpose of equalizing temperature.

In the furnace shown in Fig. 283 the sheet bars can either be piled up and pushed through in piles, or else they can all be made to stand on edge, except near the discharge end, where they will topple over, with the last one lying flat. This circumstance is quite likely to produce climbing and irregular piling. However, the nearness of the discharge door makes it possible to correct this trouble with little effort. If too much inconvenience arises from this method of handling the sheet bars they can, as above mentioned, be pushed through the furnace in piles with an occasional sheet bar standing on edge between the piles for the purpose of preventing climbing or irregular piling.

While the furnace in question produces very uniform heating, on account of the passing of products of combustion between the sheet bars, it is open to an objection which is common to all furnaces with water-cooled skid pipes, namely, the occurrence of "black spots." However, this trouble is almost entirely eliminated in the furnace under discussion by making the skid pipes double, which means that a small water-cooled pipe lies inside a larger pipe which is directly cooled by radiation to the smaller pipe. On account of the low temperature existing in pair furnaces, indirect cooling of the skids is possible. It is claimed that this design does away with black spots.

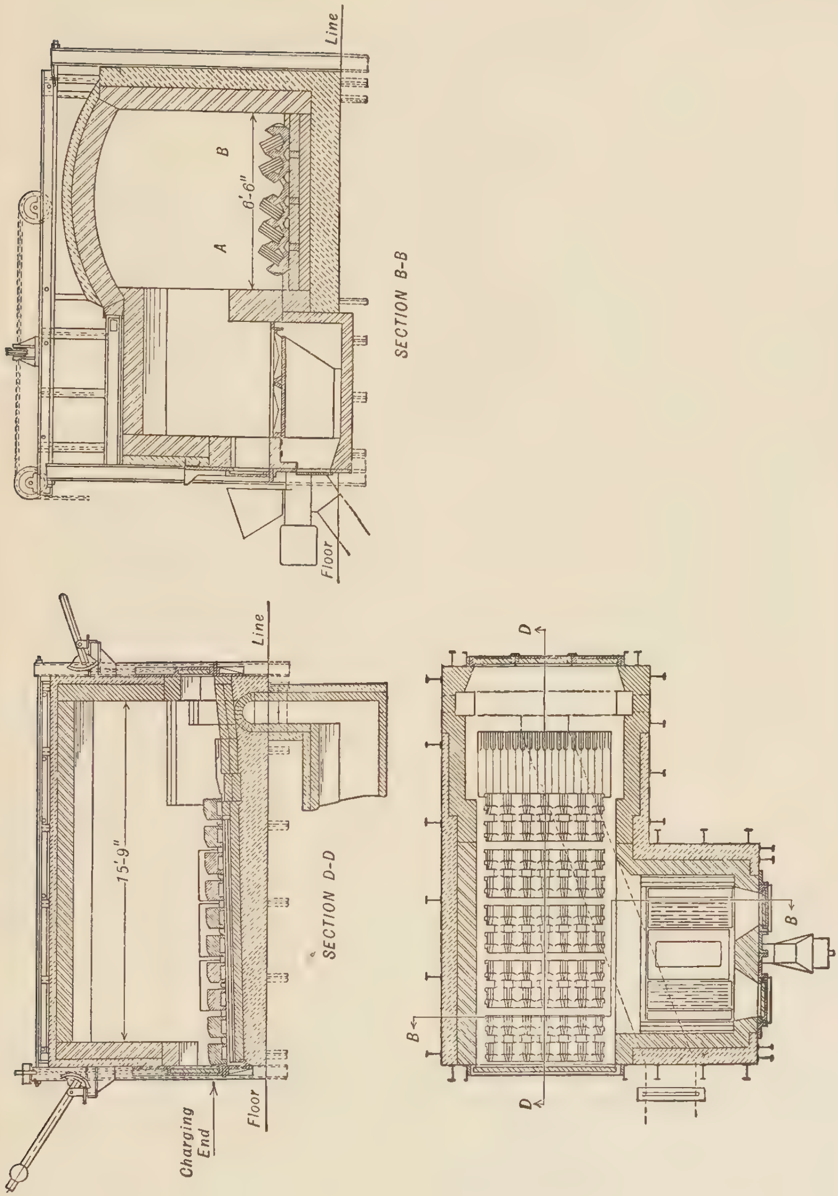

FIG. 282.—Continuous pair furnace with metallic hearth.

The arrangement of the continuous pair furnace just described, in relation to the sheet furnaces and to the mills, is shown in Fig. 284. It will be noted that the sheet bars, or pairs, must be dragged a considerable distance to the mill. This disadvantage is

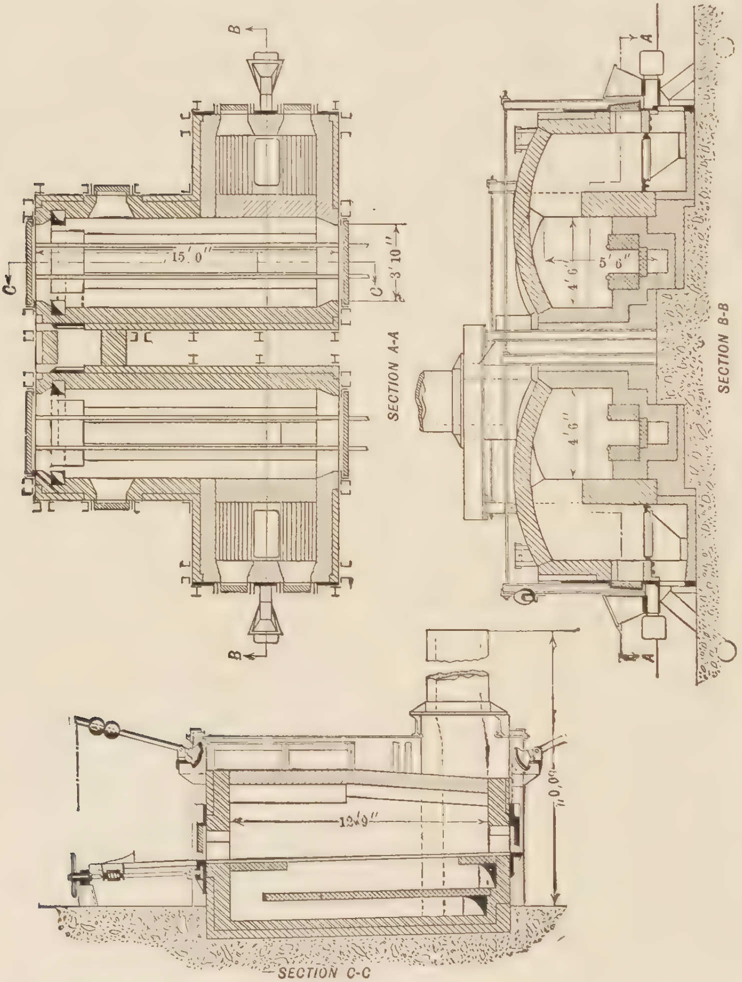

FIG. 283.—Stoker-fired continuous pair furnace with circulation of gases under sheet bars.

counteracted by the large hearth area which is available for the heating of sheets. Mill capacity is limited by furnace capacity, and rapid heating on a small hearth results in a poor grade of sheets.

It will be noted that both types of furnaces, those of Fig. 283 and those of Fig. 282, are fired by bituminous coal burned on underfeed stokers. This point will be discussed later, in connection with the selection of fuels for sheet and pair furnaces.

In spite of the advantages which any labor-saving furnace offers the furnaces described and illustrated in Figs. 282 and 283 have not been universally introduced. This fact is doubtless due to local conditions existing in some of the plants. There are mill managers who contend that the labor-saving features of these two furnaces are only an imaginary advantage, because the wage

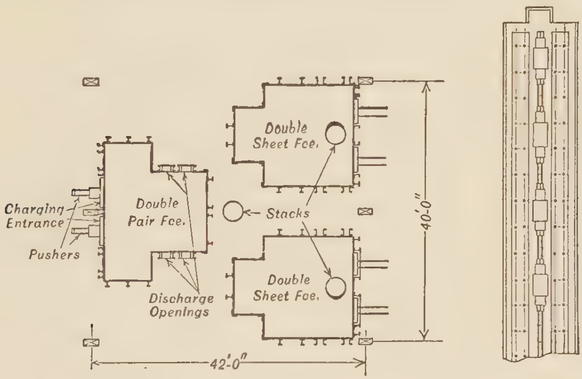

FIG. 284.—Arrangement of sheet and pair furnaces with relation to mill.

schedule calls for a given wage per ton for heating, regardless of the type of furnace. These mill managers reason that, if you pay a man a good wage for heating, you might as well make him work for it, particularly if the labor-saving furnace costs considerably more than the ordinary furnace on account of the royalty which must be paid on its patented features. Another feature which is regarded as a disadvantage of these furnaces, but which can hardly be of deciding importance, is the amount of sheet bars left at the end of each turn. On account of the pushing feature it is impracticable to empty the furnace at the end of each turn; and rollers object to handling steel which has been left in the furnace from the preceding turn. In part, this objection may be explained by the time which must be spent while the rolls are being polished at the end of each turn. During that time scaling of the sheet bar in the furnace is liable to occur.

Furthermore, many heaters prefer to start their turn with an empty furnace and to give their rollers pairs which they themselves have heated rather than be held responsible for results which may have been affected by the heating on the previous shift. This preference is due to the effect which uneven heating has on the quality of sheets produced. In starting a new turn, no time is lost in putting cold pairs into the empty furnace, because they can be heated while the rolls are being polished. It is furthermore claimed that these continuous furnaces are not truly continuous, but somewhat intermittent, because they do not work or discharge steel while sheets are being rolled. As a rule, the same crew does the rolling of pairs and the rolling of sheets. That is to say, while a furnace full of sheets is being worked out there can be no steel taken from the pair furnace. Evidently, the best utilization of the continuous pair furnace would require a modification of the practice of rolling as it exists in many plants; this fact may account for the lack of general adoption of these furnaces.

For all of these reasons, duplicate furnaces arranged side by side as shown in Fig. 281 or in Fig. 285 are installed in most of the mills, one side serving for heating pairs and the other for heating sheets. In those mills in which thin gages are rolled two sheet furnaces are required for one pair furnace.

From the above statements it is evident that, in this case, usage in the method of rolling in vogue in different plants, together with certain peculiarities of the wage scale, has more influence in the selection of the type of furnace than any other element. The reasons for the selection of furnaces such as that illustrated in Fig. 285 were, at least in part, discussed on pages 305 and 306 of Volume I. In this section they must be enlarged upon for a more thorough understanding of the reasons why this type of furnace has persisted to the present day. Pairs and packs of sheets must have a very uniform temperature throughout their thickness and over their whole area. If the outside has attained the right temperature and there is still a cold core, the pressure between the rolls and the steel becomes so great as to injure the structure of the steel, and to roll scale into the steel, besides causing pitting and marring of the rolls. There is therefore needed not only a very even temperature at all parts of the furnace hearth, but also a furnace and wall temperature very

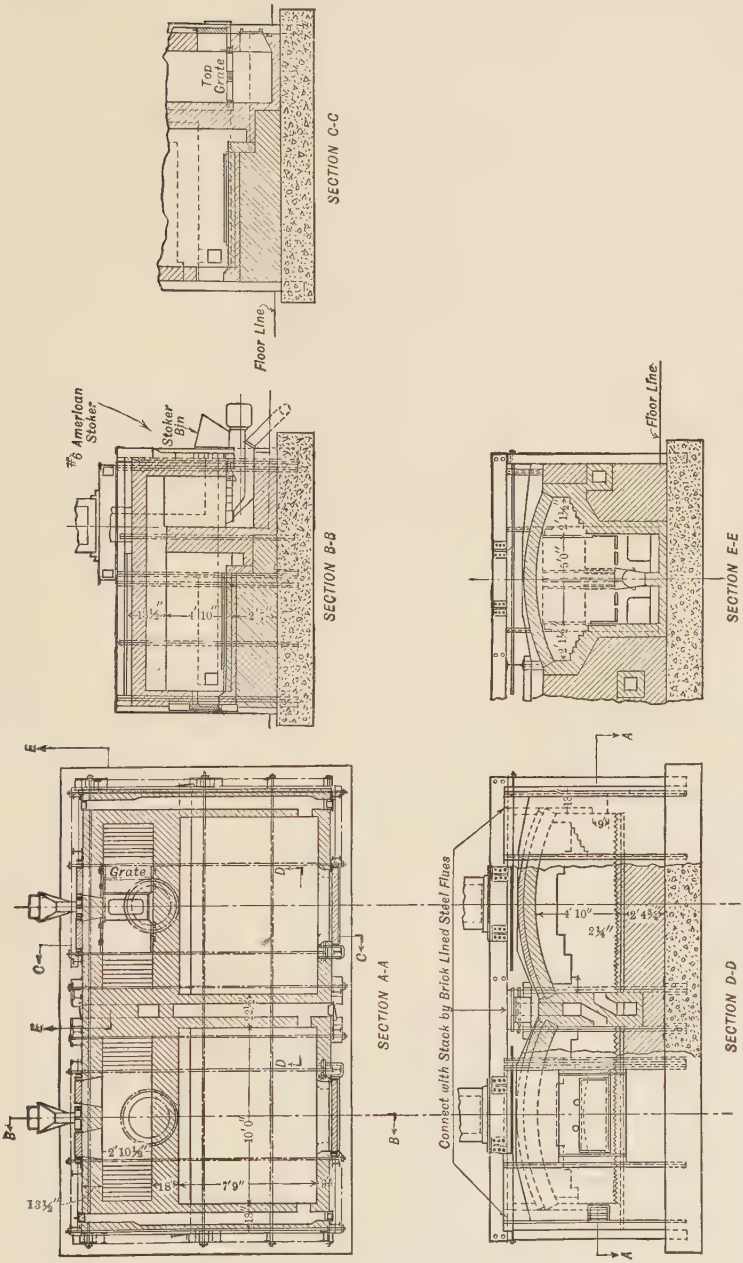

FIG. 285.—Stoker-fired sheet and pair furnace with separate stacks.

slightly in excess of that which the sheets should have when removed from the furnace.

In Wales, where the sheet furnace was invented, bituminous coal was the only fuel available at that time. It was burned on a small grate, and the products of combustion rose from the grate in almost parallel lines to the top of the bridgewall, where they flowed along the ceiling or roof of the heating chamber and finally passed into flues near the door. As the walls of the combustion chamber radiated and otherwise lost a certain amount of heat, the products of imperfect combustion, upon reaching the top of the bridgewall, were not excessively hot. Combustion continued as the gases rolled along the roof, and was fairly complete by the time they passed down into the flues in the hearth, directly at the door. The arrangement of these flues at the door is shown in Fig. 286. Continuance of the combustion throughout the furnace and near the door caused the hearth to have a practically uniform temperature. The sheets lay in a more or less stagnant furnace atmosphere with only secondary circulation. They could be placed anywhere on the hearth without fear of overheating or of excessive scaling. The manner in which incomplete combustion with uncombined air above the grate was obtained in these furnaces is fully described in the chapter on "Combustion Devices for Solid Fuel," and need not be repeated here.

The arrangement of the flues under the hearth, as shown in Fig. 286, was intended to produce a hot hearth, for the purpose of imparting, to the sheets, additional heat from below. This latter feature, which is a very good one in the hands of skilled heaters, did not always work out as well as intended, because a slight misadjustment of the damper would draw cold air from the door opening into the flues and would chill the products of combustion in those flues to such an extent that they would absorb heat from the hearth rather than impart heat to it. It may be argued that this feature is not due to defective design but to the unreliability of the human element. However, there proved to be so many heaters who did not know how to adjust the dampers properly that the under-bottom flues resulted, altogether too often, in a cold hearth and were, for that reason, abandoned in the United States.

Hand firing is distasteful to many people, inasmuch as it

requires not only attention and skill, but also physical labor. Besides, it does not allow "pushing the furnace." For that reason mechanically operated underfeed stokers, such as those indicated in Figs. 282, 283, and 285, were applied to quite a number of sheet and pair furnaces. The stokers have the great advantage that they can burn a very cheap coal, whereas hand

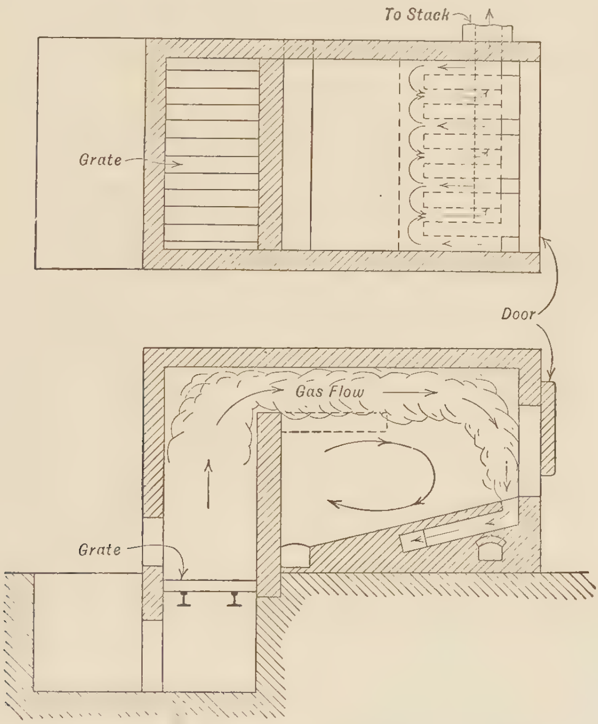

FIG. 286.—Sheet furnace with flues in hearth.

firing requires good lump coal. Besides, it has been found possible to heat sheets with 100 to 150 pounds of coal, per ton of sheets, less than if hand firing were used. However, the stoker requires just as careful operation as hand firing does; as a matter of fact, some heaters state that it requires even more careful attention than hand firing. If it is properly adjusted and if the ash-pit doors are kept closed blast from the tuyeres probably escapes into the ash pit and crosses the grate bars again, farther

from the center. On account of the cheaper fuel which can be burned on stokers and the reduced fuel consumption, they will probably continue to be used; but it has been found that, in order to do good heating, it is at times necessary to throw green coal on top of the fuel bed of stoker-fired furnaces, for the purpose of producing the correct atmosphere in the furnace, and to obtain the kind of radiating flame sketched in Fig. 286 of this section. If the stoker is operated in the same manner as a boiler stoker the sheet furnace has very bright, hot spots immediately above the bridgewall, while the front end of the furnace near the door is too cold. Clean-out doors above flue fuel bed must be absolutely air-tight.

Since both hand firing and stoker firing require the careful attention of the heater, in addition to physical labor, which is not very pleasant around a hot sheet mill, attempts have been made to use different fuels, such as producer gas, powdered coal, oil, and natural gas, for the purpose of securing better and more uniform heating with less attention and physical labor on the part of the heater. It is significant that, in spite of all these attempts, most of the sheet and pair furnaces are still coal-fired, and that many are hand-fired. One of the principal difficulties has been that of securing a furnace in which there is an absolutely uniform temperature all over the hearth. With natural gas as a fuel, the problem has been solved [1] by using a considerable number of proportional mixers and firing directly under the roof of the tall furnace, as indicated in Fig. 287. This is a rather recent development. It can be used only where clean gas, such as natural gas, or clean producer gas, is available.

If gaseous or liquid fuels are burned in a separate combustion chamber, similar to that indicated in Fig. 285, or Fig. 286, combustion is, as a rule, fairly complete when the gases pass over the top of the bridge wall, with the result that the combustion chamber is very hot and that there is a very hot spot directly over the bridgewall. The rear end of the furnace, seen from the working door, is very much hotter than the front, and the heating of the sheets is not uniform. To a certain extent, this difficulty may be overcome by a protecting arch in the rear of the furnace, as indicated by dotted lines in Fig. 286. This arch may be extended

[1] There are rollers who claim that gas firing is not as well adapted to the making of high-finished sheets as coal firing.

quite a distance, and may be perforated, to secure a still more even distribution of temperature. The difficulty of this expedient is that the free end of the arch has a tendency to collapse.

Powdered coal has been tried repeatedly as fuel for sheet and pair furnaces, but it was not found to be an unmixed blessing. Perhaps it was most natural to put powdered coal into the same combustion spaces which had formerly been used for coal on the grate. Wherever that experiment was tried it resulted in failure, because not enough volume was provided for complete

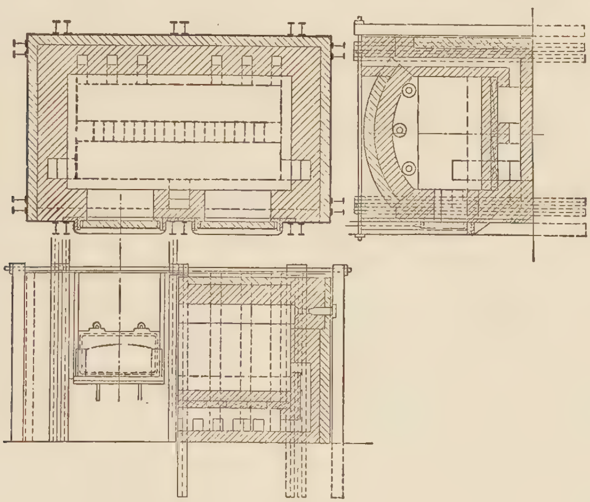

FIG. 287.—Gas-fired pair furnace.
Compare also Fig. 139.

combustion of the coal particles, and for dropping out the heavy ash particles.

One of two things had to be done. Either powdered coal had to be discontinued or else the combustion space had to be enlarged. The former was done in quite a number of works, in which powdered coal was thereafter considered a pronounced failure. The second course was taken in a comparatively small number of works, in which the engineers, managers, and superintendents battled and fought to save the investment, and incidentally their jobs and reputations. An illustration of a sheet furnace with an extended combustion chamber is given in Fig. 288. This illustration represents a double furnace with a dividing wall.

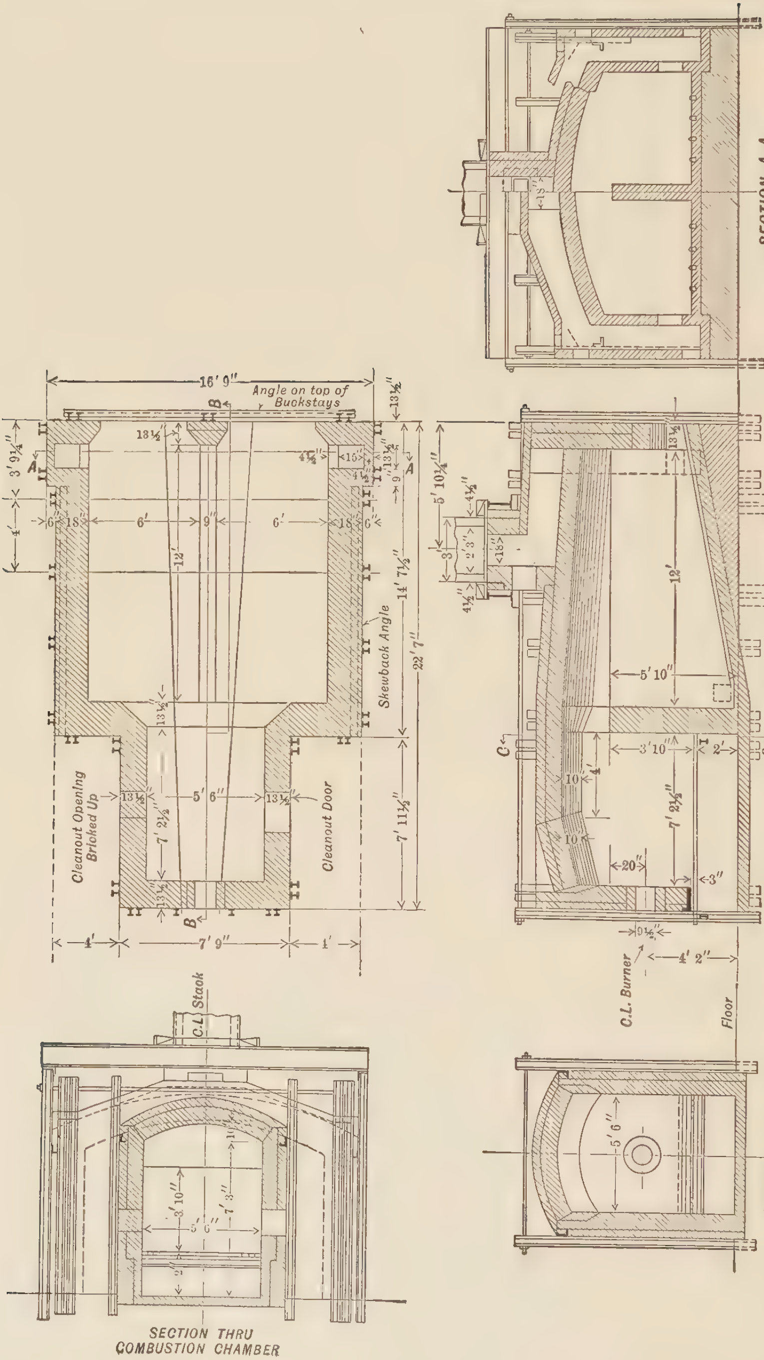

Fig. 288.—Double shell furnace with extended combustion chamber for powdered coal.

It will be seen that the combustion chamber has a considerable volume and is quite long compared with those shown in Figs. 285 and 286. The longer the combustion chamber, the better it is adapted for burning powdered coal, because the amount of ashes carried over into the heating chamber proper is reduced very much by a long combustion chamber. Hot spots can be prevented by the method explained in the preceding paragraph.

In those sheet mills in which powdered coal is used today it has been found that, with long combustion chambers, with fine, uniform grinding, and with a good coal, low in sulphur and low in ash, very excellent sheets can be made down to about No. 22 gage, and that a sufficient uniformity of heating can be obtained. The temperature immediately above the bridgewall is fairly high. The particles of ash that pass over the bridgewall are swept up against the hot roof and stick there, forming a loose conglomeration which looks somewhat like whiskers. These "whiskers" act as a catching device for ash particles, which would otherwise pass over into the heating chamber where they would fall on the sheets and cause trouble in the mill. They are removed once every turn. Where the above-mentioned conditions (long combustion chamber, uniform grinding, coal low in ash and sulphur) exist, powdered coal makes a satisfactory fuel for sheet and pair furnaces, particularly if combustion is incomplete in the combustion chamber. In well-operated sheet and pair furnaces fired with powdered coal, blue flames, due to the combustion of carbon monoxide, can be observed in the heating chamber.

With gas firing, the hot spots over the bridgewall, with the attendant troubles which have been repeatedly mentioned in this section, and for which an arch near the bridgewall was given as a possible remedy, can be, at least in part, obviated by another device, namely, that of a hollow bridgewall. Figure 289 shows an old method of burning natural gas in sheet and pair furnaces. Gas with some air burns very incompletely in the combustion chamber. Through the double bridgewall additional air is admitted, so that, at the top of the bridgewall, a secondary combustion is initiated. As mixing of combustible gases and of secondary air is not complete at the top of the bridgewall, the desired slow flame, extending all the way over to the door, is obtained. With producer gas this arrangement should likewise

work well, but with oil it would cause trouble. It may be mentioned that in the furnace shown in Fig. 289 the sheets lie on a coke bottom. From the preceding description it is manifest that the choice of furnace types for heating sheet bars and sheets is extremely limited. New types may, in time, appear, and one or two of them may survive, if history repeats itself. The patent records are full of sheet and pair furnaces, but most of these furnace inventions were abandoned after a short time.

Heat-treating Furnaces.—The term "heat treating" covers a multitude of operations. In the heat treatment of steel it applies to "drawing," which is done at temperatures of steel between 700° and 1200° F.; to heating for quenching, which is done at

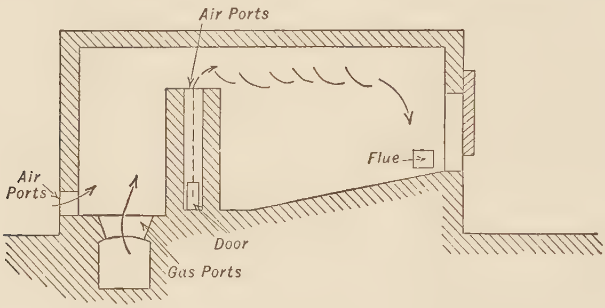

Fig. 289.—Sheet furnace fired by natural gas.

temperatures in the neighborhood of 1400° F.; to annealing, which calls for a temperature of 1600° F.; to carburizing, which takes place between 1700° and 1800° F.; and to the treatment of high-speed tool steels, which requires a temperature of 2200° F.

General-utility Furnace.—In all-around machine shops occasions may arise, from time to time, for doing any one of these heat-treating operations, and on different sizes of work, from a small twist drill to a fairly large gear. By a process of elimination the choice of fuels narrows down to city gas, water gas, oil, or natural gas. In the future electricity may also be considered; but at present electrically heated furnaces for a wide range of temperature are not available. Natural gas will doubtless be used if available all the year round. If natural gas is out of the question, city gas is the best choice, unless the shop is part of a plant

which is equipped with a water-gas generator. Oil remains as a last resort if the other fuels are not available. The price of fuel per million heat units counts very little in a case of this sort, because the fuel cost is usually less than one per cent of the total shop cost of the finished piece. What counts is the possibility of generating, at will, much or little heat in a confined space, without injury to the material being heated. For that purpose, rich, clean, cold gaseous fuels are eminently suitable. If the shop is so

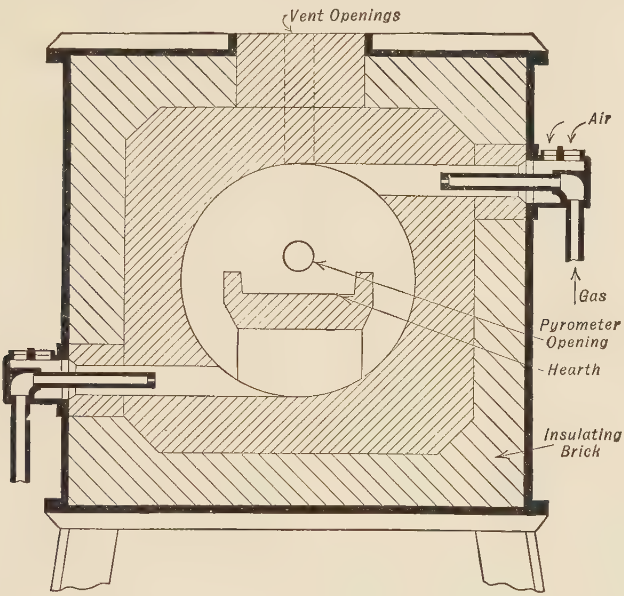

Fig. 290.—General utility furnace for heat treating. It can be used for a great variety of work and a wide range of temperatures.

located that oil must be used, gasification and vaporization of the oil on its way to the furnace is very much to be recommended. Properly vaporized light oil (26 to 32 degrees Baumé) burns exactly like city gas.

With regard to type of furnace, horizontal heating, with the work resting on a hearth, is the only possibility for a great variety of work and for a wide range of temperatures. Some of the work should, for best results, be suspended vertically, but, in a furnace for all-around use, that desirable feature cannot be had. On

account of the wide temperature range desired in this case the burners and furnace should preferably be arranged as indicated in Fig. 290. Six burners produce a rotating whirl of products of combustion. Venting takes place through the roof and around the door. For low-temperature work tiles are placed on the roof, and partly cover the vents. Figure 291 shows the shape of the hearth-tile, with the ducts for flame circulation. The combustion space is so small that no other fuel but gas or vaporized oil will do.

If the furnace is to be used for a wide range of temperatures the supply of gas and air needs consideration. Premixing of gas and air by a proportional mixer is desirable, but trouble may arise through back-firing (back-lighting) at low rates of flow (low temperatures). If sufficient regulation can be obtained by shutting off the upper burners and by turning down the flow as far as is safe, premixing of gas and air in correct proportions can be practiced. If a sufficiently low temperature cannot be reached by these means a gas-and-air mixture which contains less than the correct amount of air is delivered to the furnace, and the rest of the air is induced at the burner. This arrangement is shown in Fig. 290.

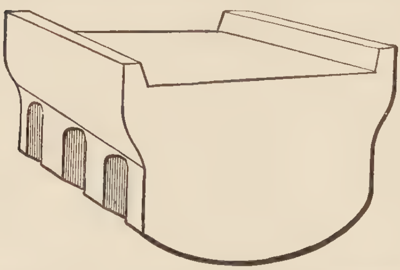

FIG. 291.—Hearth of furnace illustrated in Fig. 290.

Note the ducts for circulation of products of combustion.

Single-purpose Furnace.—As a shop grows, other types and sizes of furnaces for heat treating are added. A discussion of the methods of selecting these various types will not be attempted here, because this chapter is devoted solely to examples, which are selected from the wide field of industrial heating. In accordance with this policy an example will be selected to illustrate the other extreme (opposed to general utility), namely, the heat treating of automobile parts in a factory producing them in large numbers. The example refers to that work in which the temperature is about 1400° F. for the first heating and about 1180° F. for the second heating. Ten years ago, when all heat-treating

furnaces were fuel-heated, it was customary to do the heating in a separate building, or at least in a separate aisle; in this manner the heating work, with its heat, dirt, and fumes, was kept away from the machine shop. Oil was the favorite fuel, because its cost per unit of heat was much lower than that of other fuels, except coal or coke, and the latter were very seldom used on account of the cost of skilled attendance. Ashes and dirt, which are inseparable from coal and coke, likewise favored the elimination of these fuels. Furthermore, heat treating with coal requires a modified muffle construction, with ascending and descending flues in the walls and heat transfer through the walls into the heating chamber.

The high temperature of the oil flame had to be reduced by the various means explained in other chapters, usually with considerable loss of heat. In consequence, the heat in the steel lay between the limits of 5 and 25 per cent of the heat in the fuel and exceeded that value in a few exceptional cases only. A characteristic oil-heated furnace of that period is shown in Fig. 292. It is of the continuous type, pusher-operated. While oil has retained its supremacy for the heat treating of heavy pieces, its use for quantity heat treating of automobile parts has not advanced, and may have gone backward. Clean producer gas, city gas, and electrical energy are taking its place to a very large extent. The flexibility of gas firing and electrically energy is greater and labor costs are less.

As long as the shop is small and each furnace heats a variety of shapes and weights a separate heat-treating department is appropriate; but as the shop grows and each furnace handles one particular part only, the advisability of placing the furnace directly in the production line is given consideration. At that point electrical heating frequently replaces fuel heating. While the cost of electrical heat is often high, little of it is lost; the furnace exterior is not uncomfortably warm; there are no obnoxious fumes. An electrically heated furnace is easily re-located; a cable can be strung almost anywhere. Accurate and automatic temperature control (needing no attendance) is easily obtained. Energy costs per unit weight of heated material are definitely known. Electrical heat for heat treating reduces labor costs and costs of rejections. Correct data on these items are difficult to

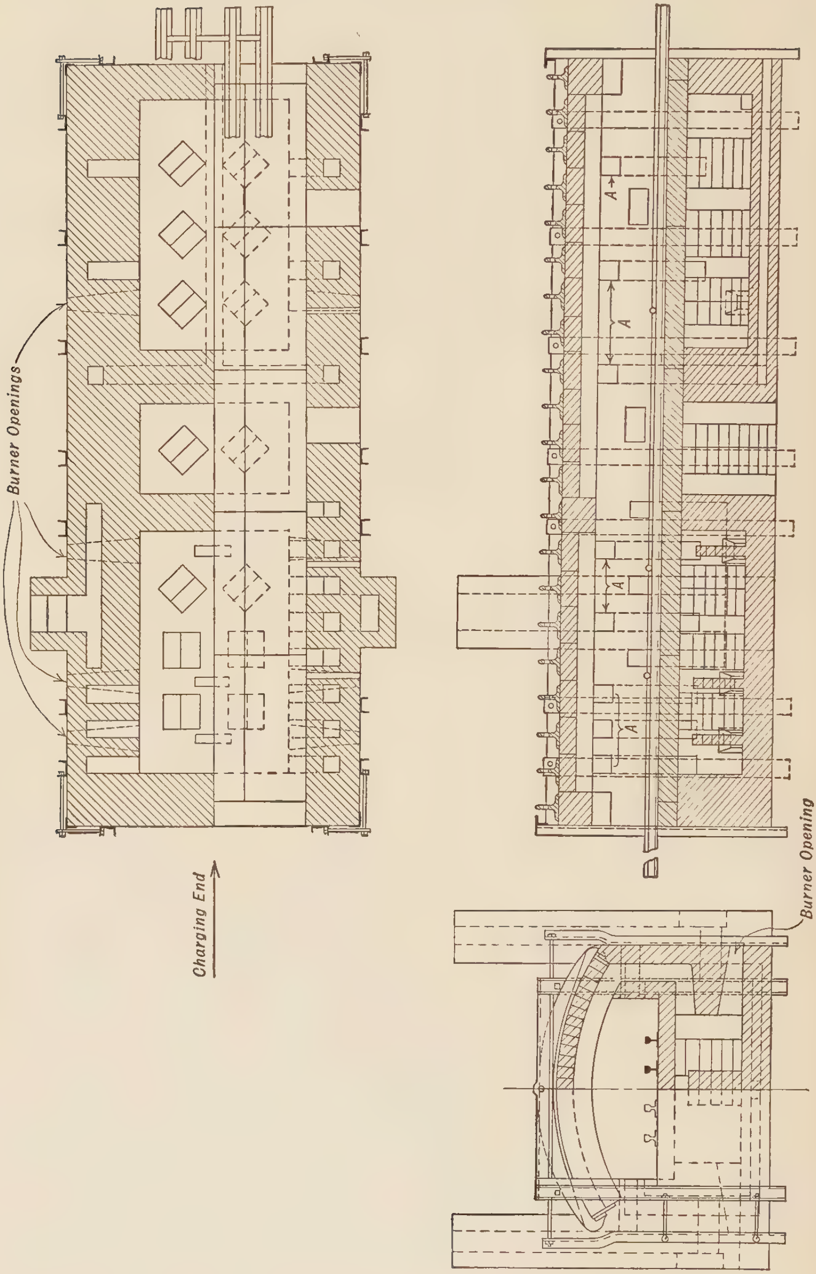

FIG. 292.—Oil-fired heat-treating furnace. Underfired or semi-muffle furnace of the continuous type, pusher-operated.

obtain;[1] however, it has been estimated that, while in the heat treating of transmission gears with oil fuel there is 3 per cent scrap and 12 per cent retreatment, with electrical heat there is only 2 per cent scrap and 4 per cent retreatment. It should again be noted that a careful and experienced heater can keep the percentage of spoiled material just as low with oil as with electricity, but only by exercising great vigilance. In that case the labor cost is high.

In automobile works which have been in existence for ten years or more most of the recent furnaces are electrically heated. An exception is made in the heating of those parts which must not scale; for such parts city gas with a reducing atmosphere is frequently preferred. The total costs (heat energy and labor) with electrical heating and with city gas are not far apart. The rates at which the two kinds of energy are available in different localities and on different scales determine which one is cheaper. A comparison made by a company which produces an accessory used with most of the automobiles in the United States gave the results printed in the tabulation on page 388.

Under the conditions existing at the shop in question it was more economical to use city gas. The conclusions are naturally affected by furnace design and by energy rates.

A study of the figures shows that, with a rate of one cent per kilowatt-hour, the energy costs would be practically equal, if the gas rate remained unchanged; and that with a rate of one cent per kilowatt-hour, electricity would be cheaper, if gas cost one dollar per 1000 cubic feet.

A non-scaling atmosphere can be obtained in electrically heated furnaces by spraying the parts with oil, as mentioned in Chapter IV. The same result may be obtained by burning purified water gas at the doors of the furnace. In either case the simplicity is gone and labor is required; and furthermore, carbon is deposited on the surface of the heating elements, causing trouble.

With regard to the furnace type for mass production it is

[1] The *Transactions of the American Society for Steel Treating* contain a mass of data on comparative costs of installation and of operation of fuel-fired and of electrically heated furnaces for heat treating, particularly in the years between 1920 and 1924. Almost invariably, the overall, final cost of heating is stated to be less with electricity than with any other source of heat, with the exception of city gas and natural gas.

Analysis of Operating Data of Gas-fired and Electrically Heated Oven Furnaces under Parallel Working Conditions

	Electrically heated furnace	Gas-fired furnace
Time for heating up	$1\frac{1}{2}$ hours	$1\frac{1}{2}$ hours
Allowing for lunch	....	$\frac{1}{2}$ hour
Actual operating time	$7\frac{1}{4}$ hours	8 hours
Output during operating time	2890 magnets, weighing $433\frac{1}{2}$ lbs.	4080 magnets, weighing $637\frac{1}{2}$ lbs.
Size of work	Outside diameter. $1\frac{11}{16}''$; inside diameter, $1\frac{1}{8}'' \times \frac{7}{16}''$	Outside diameter, $1\frac{11}{16}''$; inside diameter, $1\frac{1}{8}'' \times \frac{7}{16}''$
Working temperature	1600° F.	1600° F.
Number of charges	17	24
Magnets per charge	170	170
Time required per charge	25.6 minutes	20 minutes
Energy consumption for heating up	From 1140° to 1600° F., 30 kw.-hrs.	From 800° to 1600° F., 628.58 cu. ft. of gas
For operating time	120 kw.-hrs.	1980.75 " " " "
Total	150 kw.-hrs.	2609.33 " " " "
Energy cost total	† At $1\frac{1}{2}$¢ per kw.-hr., $2.25	At 71¢ per 1000 cu. ft., $1.85
		For compressor power share, ‡ $\frac{1}{2}$h. p.. = .373 kw.-hr. × 10 hrs. × $1\frac{1}{2}$¢ = 5.6¢ Total, $1.91 †
Energy cost per 1000 magnets	78¢	47¢
Fuel cost ratio	* 1.66 to	1
Production for 8 hours operating time	18.75 charges × 170 = 3190 pieces	24 charges × 170 = 4080 pieces
Production ratio	* 1 to	1.28 Gas furnace gains every 3.6 days one full 8-hour operating time day production of electric furnace plus one operating day fuel and labor expense of electric furnace.
Labor cost ratio	1.28 to	1

* The fuel and production ratios do not take account of energy consumption of electric furnace during lunch period.

† Data assumed.

‡ Estimated.

evident that nothing else but a continuous furnace will be satisfactory. In the first heating (1400° F.) the parts are either pushed through directly or on trays, or else they are transported by rocker bars. In the second heating (1200° F.) the parts are either pushed through the furnace or else conveyed on a chain. The method of transportation, within these groups, depends upon the size and the shape of the pieces.

While the example on p. 385 seems to indicate that oil is no longer a useful fuel for heat treating it proves to be the right fuel for that purpose under different plant conditions. The heat treating of heavy material, such as ship shafts, die blocks, steam turbine discs, steam turbine drums and shafts, etc., differs in several decisive factors from the heat treating of comparatively light automobile parts in large quantities. The heavy parts need considerable heat, and the surface to be machined is small compared with the weight to be heated. In consequence, fuel costs are a greater item in the total cost than they are for the lighter parts. The heavy parts are heat treated either before any machining has been done or else before the finishing cut is taken. A moderate amount of scaling or pitting is quite harmless. The quenching of heavy pieces is anything but automatic; it requires labor, which can be utilized for attending oil burners and auxiliary equipment, while the pieces are being heated. The more or less intermittent use of the large furnaces makes heavy investment charges (such as are needed for electrically heated furnaces) quite undesirable. Furthermore, the cost of great quantities of electrical energy for intermittent use is almost prohibitive. On account of these various factors the fuel for heat treating of heavy parts is either natural gas, when it can be had at a reasonable rate, or fuel oil. In localities where neither natural gas nor inexpensive oil can be obtained coal, coke, or producer gas is used for the heat treating of heavy pieces.

It is hoped that the examples given in this chapter are representative and will point the way which is to be followed in each and every individual case. Only by careful study of all the plant conditions and of every available fuel and furnace type can the right conclusion be reached.

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